Saskatchewan
Energy and Mines

Miscellaneous Report 85-4

Summary of Investigations 1985, Saskatchewan Geological Survey

Printed under the authority of the
Minister of Energy and Mines

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Typesetting and paste-up by Brigdens
Reprographics for text figures and maps by General Graphic Services Ltd.
Printed by Saskatchewan Government Printing Company

ISBN 0228 5657

Foreword

The surge in oil and gas drilling activity in the southern part of the province has continued unabated during the past year. The Saskatchewan Geological Survey's efforts in connection with this surge have continued to concentrate on updating the well file and other databases, but also to pursue some project work on the oil-bearing strata as described herein.

In 1984 an undertaking was made to promote exploration into gold and precious metals in the northern part of the province, and accordingly a "Gold Belt Geology" program was initiated in the Precambrian Shield area. The operational funds for this geoscience program are derived under the five-year Canada-Saskatchewan Economic and Regional Development Agreement, Subsidiary Agreement on Mineral Development 1984-89. This program is being mounted jointly by the federal and provincial agencies on a 50:50 "parallel delivery" basis. The gold play in the La Ronge Belt and neighbouring areas by industry is now in full stride, lending due relevance to the program.

A large part of this year's Summary of Investigations is concerned with these northern studies. We are grateful for contributions from the Geological Survey of Canada, principal geoscientific partner in the federal-provincial program, as well as from the Saskatchewan Research Council, Carleton University, The University of Kansas, the Universities of Saskatchewan and Regina, and others, including descriptions of some projects not funded under the geoscience program.

J.E. Christopher
Director
Saskatchewan Geological Survey

October, 1985

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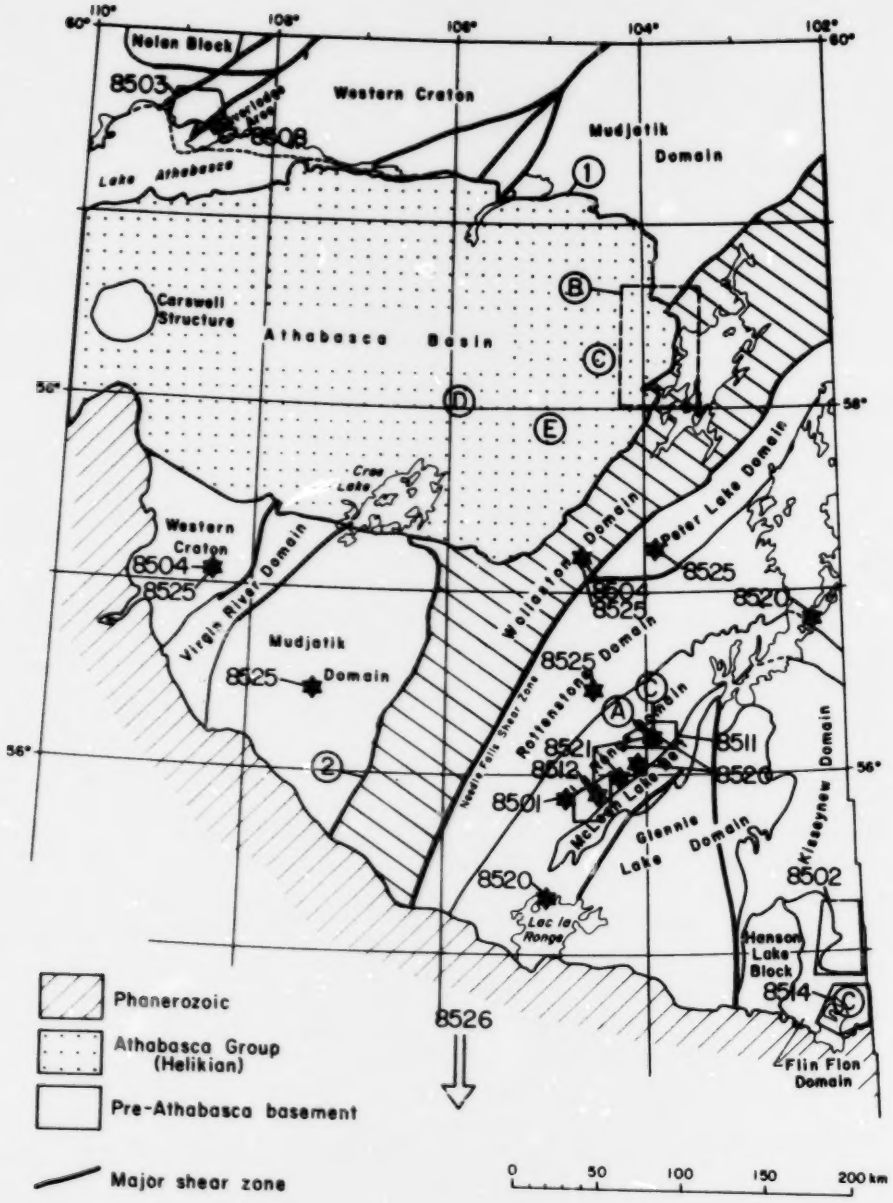

Figure 1 — *Location of projects or reports in hand. Numbers or letters on map refer to project numbers or letters listed opposite.*

Introduction

by R. Macdonald and T.I.I. Sibbald

As last year, a large part of the Summary of Investigations is concerned with projects mounted under the five-year Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89, now in its second year, which provides largely for geoscience surveys and studies.

The provincial part of the agreement includes a potash geology project presently being initiated, and a major component comprising mainly field-based projects under the heading of the "Gold Belt Geology" program. The Gold Belt Geology projects include 1:20,000 scale geological mapping with supporting geochemical, isotopic and geochronological studies, as well as Quaternary geology and mineral deposit studies (Fig. 1). Complementary to these field and laboratory investigations are ongoing programs of bedrock and metallogenic compilations as a map series at 1:250,000 scale (Fig. 2). A comprehensive index of the maps and reports published or open filed is given in the Precambrian Mapping Index in the accompanying package.

The federal geoscience component of the agreement, being undertaken by the Geological Survey of Canada, comprises mainly airborne geophysical and lake sediment geochemical surveys, as well as mineral deposit studies and one thematic regional geological study. The GSC has provided a number of contributions, which report progress of most of their activities.

The section entitled "Other Northern Studies" contains contributions from other organizations, and includes a recent review of the geology and genesis of the Athabasca Basin uranium deposits. The section entitled "Southern Studies" includes contributions from the Petroleum Geology Section and a progress report on the first work for some years on the subsurface Precambrian basement rocks of the southern part of the province.

Gold Belt Geology Program

Bedrock mapping at 1:20,000 scale was continued south from both the Waddy and Star Lake areas along the Central Metavolcanic Belt of the La Ronge Domain (projects 8511 and 8512, C.T. Harper and D.J. Thomas). Mapping of the belt, now in its second year, is expected to be completed to as far south as Missinipe by the end of the third year. D.J. Thomas, notably, has mapped a large area of sill and associated intrusives, defined several pluton types and produced a number of tentative geological criteria for gold exploration in the area.

Project Number	Area/ Short Title	Project Leader	Notes
MDA Projects and Contracts:			
8521/ 8501	Forbes Lake Geochemistry	B.R. Watters and R. Macdonald	3
8502	Kisseynew Geochemistry	G.R. Parslow and J.W. Gaskarth	3
8503	Martin Sedimentology	P.K. Mazinka and H. Henry	3
8504	U-Pb Geochronology	M.E. Bickford and W.R. van Schmus	3a
8505	Mineralized Core Collection	A.J. Gracie	2
8508	Rb-Sr Geochronology	K. Bell and M. Bikerman	3
8511	Geological Mapping, Waddy-Tower Lakes Area	C.T. Harper	1
8512	Geological Mapping, Roundish-Bervin Lakes Area	D.J. Thomas	1
8514	Gold Studies, Southeastern Shield	J.G. Pearson	6
8520	Biogeochemical Studies	C.E. Dunn	1
8521	La Ronge Geochemistry	B.R. Watters	3
8524	Quaternary Geology Report	B.T. Schreiner	3a
8525	Nd-Sm Isotope Geology	K.D. Collerson and J.F. Lewry	3
8526	Sub-Phanerozoic Basement Studies	J.F. Lewry and K.D. Collerson	4
1	Athabasca Basin Report	P. Ramaekers	3
2	Wollaston Belt Report	W. Coombe	3
Other Northern Studies:			
A	Quaternary Geology, Waddy Lake Area	J.E. Campbell	5
B	Wollaston Lake Landsat Study	S. Aronoff et al.	5
C	Uranium and Gold Signatures	M. Mellinger	5
D	Lighogeochemistry, Athabasca Group	D.H. Quirt	5
E	Geology of Athabasca Uranium Deposits	T.I.I. Sibbald	6

1 Field project in 1985 (1a is part field project)
2 Projects covering more than one location (not shown on map)
3 Contracted project 1985-86 (3a joint venture agreement)
4 Project partially supported by SEM in 1985-86
5 Externally contributed report
6 Final reporting this year

Especially worthy of record from C.T. Harper's area is the identification of two major zoned composite plutons (Brinson Lake and Boundary) Lake which, because they are similar to the Star Lake pluton, present good exploration targets.

The mapping is being complemented by lithogeochemical studies (B.R. Watters, University of Regina, project 8521; B.R. Watters and R. Macdonald, project 8501) and in part by a variety of geochronological and isotopic studies (K. Bell and M. Bikerman, project 8508; M.E. Bickford and R. van Schmus, project 8504; K.D. Collerson and J.F. Lewry, project 8525).

As a result of the bedrock mapping and other studies, a much more detailed knowledge of the volcanic, volcaniclastic and sedimentary rocks of this belt is now available together with their metamorphic and tectonic history. Also emerging is a chemical and tectonic categorization of the plutonic rocks, and targets for gold exploration.

A geochemical study was commenced by R.G. Parslow and J.W. Gaskarth (University of Regina, project 8502) into possible extensions of the postulated 'Kisseynew Metallotect' identified in Manitoba. As well as confirming the presence of the metallotect in Saskatchewan, the authors have proposed a new model for the stratigraphic position of the Kisseynew Gneisses.

Biogeochemical investigations this year (C.E. Dunn, project 8520) have been almost entirely concerned with gold in the La Ronge Domain. C.E. Dunn's report confirms the value of this technique in exploration for gold, and includes a consolidation of work started last year.

This year the Saskatchewan Geological Survey has entered into a joint agreement with the Saskatchewan Research Council to prepare a report on the Quaternary geology of the La Ronge-Reindeer-Flin Flon triangle as a guide to a methodology for gold exploration. The report is expected to be released by Spring 1986.

The Gold Belt Geology program also includes a number of other projects which are not restricted to the La Ronge-Reindeer-Flin Flon triangle:

Reports are being prepared by consultants on the geology of the Athabasca Group (P. Ramaekers) and on the mineralization of the Wollaston Domain (W. Coombe).

P.K. Mazimhaka and H.E. Hendry extended their study of the Martin Group to cover outlying exposures, including those on Tazin Lake; this is the final year of major fieldwork.

A.J. Gracie administered the Mineralized Core Collection housed mainly in the Precambrian Geological Laboratory in La Ronge. The collection comprises core from mineral deposits in the Shield area as well as cores deemed to be of marked geological importance. A new core index was published during the year (Open File Report 85-3). The La Ronge Laboratory also houses an extensive selection of hand samples from Northern Saskatchewan's mineral deposits. Development of the Mineralized Core Collection relies heavily on the cooperation of industry.

Other Northern Studies

Included in this section of the Summary of Investigations is a report by J.E. Campbell on a survey of the Quarternary geology of the Waddy Lake area. The survey covers the same ground as C.T. Harper's bedrock mapping described in this publication. It is hoped that funds will become available to extend this Quarternary geology mapping on the heels of the bedrock mapping throughout the Central Metavolcanic Belt. T.I.I. Sibbald's contribution in this section provides a summary of the geology of the uranium deposits of the Athabasca Basin, and may help to redress the Saskatchewan Geological Survey's otherwise current lack of uranium-oriented activities.

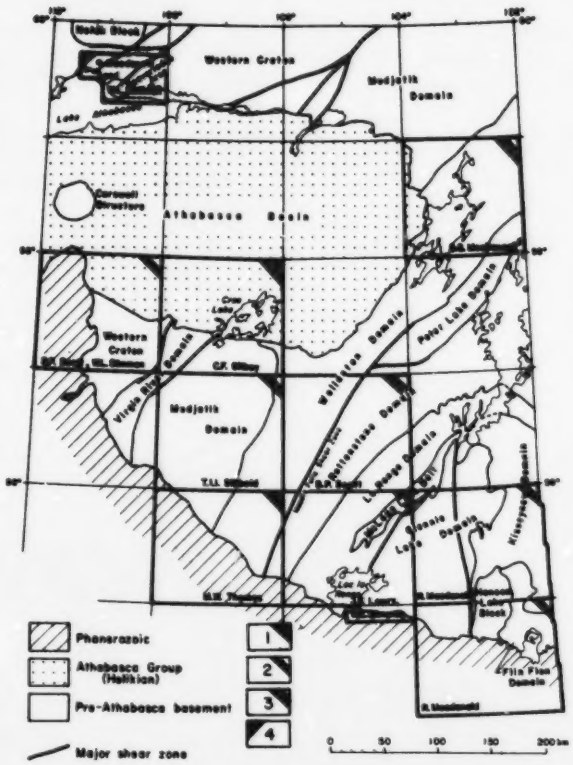

Figure 2 — *Location of compilation maps published or in progress in 1985-86. 1 = Compilation bedrock geology 1:250,000 scale final colour version published; 2 = Compilation bedrock geology 1:250,000 scale final colour version in progress; 3 = Compilation metallogenic map 1:250,000 scale in progress; 4 = Compilation bedrock geology 1:100,000 scale final colour version published.*

Compilation Maps and Data Files

The Saskatchewan Geological Survey has been engaged for some years on a program of compilation maps. Final coloured bedrock compilation maps at 1:250,000 scale are now in preparation or being released for much of the Shield area south of the Athabasca Basin (Fig. 2). These include the La Ronge sheet (J.F. Lewry and W.L. Slimmon) which contains information relevant to the gold exploration play in part of the La Ronge domain, and a coloured version of the 1:100,000 scale map of the Beaverlodge area (R. Macdonald and W.L. Slimmon).

Work continues on the 1:250,000 scale metallogenic map series (D.G. MacDougall and B.P. Scott). These maps provide details of location, metal association, development status and types of mineralization. The series uses the compiliation bedrock geology map series as a base and marginal notations are provided to develop metallogenic concepts. Two maps are currently in progress (NTS 64L and 74A).

Development and updating of the Saskatchewan Mineral Deposits Index is also ongoing (V. Harris and J.A. MacEachern). The index comprises a manual and computer listing of some 1850 mineral occurrences in northern Saskatchewan.

The Precambrian geological files and indexes (Precambrian Original Data, Precambrian Resource File, Precambrian Sample Index, and the Geochemical File) are available for consultation in Regina (N. Lee). This year the data files have been extended to include geochronological data, and a cross-referencing file of bedrock units derived from the compilation bedrock map legends. A lexicon of Precambrian stratigraphic and rock unit terms is also in compilation (R.F. Davie).

This year there are contributions from the Petroleum Geology Section on heavy oil reserves (M.A. Wilson and R.W. Bennett) and on petroleum-producing zones in the Wapella-Moosomin area (L.K. Kreis).

J.F. Lewry and K.D. Collerson have commenced a study of the Precambrian basement in deep boreholes in the southern part of the province.

GOLD BELT GEOLOGY PROGRAM (MINERAL DEVELOPMENT AGREEMENT)

Project 8511

Bedrock Geological Mapping, Waddy-Tower Lakes Area (Part of NTS 64D-4 and -5 and 74A-1 and -8)

by C.T. Harper

Harper, C.T. (1985): Bedrock geological mapping, Waddy-Tower Lakes area (part of NTS 64D-4 and -5 and 74A-1 and -8); *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The geology of an area of approximately 255 km², which covers portions of NTS sheets 64D-4 and -5 and 74A-1 and -8, was mapped at a scale of 1:20,000. This mapping represents a continuation of the 1:20,000 scale revision mapping begun in 1984 in the Waddy Lake area and includes completion of unmapped portions of the Waddy Lake North and South sheets (Harper, 1984) and the adjoining Tower Lake area to the west (Fig. 1).

The Waddy-Tower Lakes area is accessible by float-equipped aircraft from La Ronge and Missinipe, 160 and 80 km to the southwest respectively, as well as from Southend, 40 km to the northeast. Limited access is provided by Highway 102 and by a bush road into the Komis gold deposit of Waddy Lake Resources (Fig. 1). Conventional watercraft access is restricted to the Nistoassini-Waddy-Redhill Lakes chain with modest accessibility along Kenwood River, Dog Creek and Payn Creek in the Waddy Lake area. Farther west in the Tower Lake area, access is rather poor and difficult. Aircraft support from Southend greatly facilitated mapping in this area.

The Waddy-Tower Lakes area is characterized by generally undulating terrain, with local relief rarely exceeding 30 m. Bedrock is generally abundant across the Waddy Lake area but becomes less abundant in the Tower Lake area where the relief is typically more subdued and, as a consequence, muskeg and overburden are more extensively developed. Bedrock is also commonly masked by lichen and in places by blankets of moss up to 30 cm thick.

Geological Background and General Geology

The earliest geological mapping in the Waddy Lake area was by Alcock (1938) and in the Tower Lake area by McMurchy (1937), both at a scale of 1 inch to 2 miles. This was followed by 1:63,360 scale mapping of portions of the present map areas by Byers (1948), Miller (1949) and Gracie (1965). Semidetailed geological investigations in areas surrounding massive iron sulphide occurrences in the vicinity of Nistoassini Lake and Kirk and Hump Lakes were carried out by Harper (1974, 1976, 1983) and Coombe (1976). Coombe (1976) also examined the gold occurrences adjacent to the Byers Fault between Tower and Centre Lakes and around Waddy Lake. Mineral exploration activity has fluctuated sporadically since the mid-to late-thirties and is presently focussed on gold mineralization.

The Waddy-Tower Lakes area lies within the central portion of the northeasterly trending early to mid-Proterozoic volcanosedimentary- plutonic belt referred to as the La Ronge Domain (Lewry and Sibbald, 1980; Macdonald and Broughton, 1980; Lewry, 1983, 1984). The domain comprises a number of subdomains of which the mapped area straddles three (Fig. 1), from northwest to southeast: the Crew Lake, Central Metavolcanic and MacLean Lake Belts (Lewry, 1984). The Crew Lake Belt is characterized by psammitic to pelitic metasediments and metagreywackes with subordinate metavolcanics and metavolcaniclastics. A thick wedge of conglomerate and probable felsic metapyroclastics occurs along the southeastern edge of the belt in the northern Tower Lake area.

The Central Metavolcanic Belt comprises ultramafic to felsic metavolcanics and subordinate metavolcaniclastics. Lithogeochemical evidence indicates that the metavolcanics have a dominant calc-alkaline to less well developed tholeiitic character (Harper, 1976, 1983; Watters, 1981), with some rocks from the southern end of Lower Waddy Lake having "komatiitic to basaltic-komatiitic" affinities (Fox and Johnston, 1980; Watters 1984, 1985; Harper et al. 1985). The evidence also supports the idea of a volcanic arc origin for the Central Metavolcanic Belt.

Both the northwestern and southeastern boundaries of the belt are marked by prominent topographic lineaments and zones of more intense deformation featuring strongly developed foliations and lineations, shearing, extensional fabrics, tight to isoclinal folding, and in the vicinity of Hump Lake, truncation of lithologic units and major structures. These tectonic zones will be referred to as the Looney Lake and Redhill Lake tectonic zones for the northwest and southeast boundaries, respectively. The Looney Lake tectonic zone is a probable extension of the Alpat Lake tectonic zone identified by Thomas (1984) in the Star Lake area and the Redhill Lake zone is a probable extension of the McLennan Lake Tectonic Zone (Lewry, 1983; Thomas, 1984).

Feldspathic meta-arenites of the McLennan Group occur along the northwestern margin of the MacLean Lake Belt and structurally underlie the metavolcanics. Southeast of the McLennan Group, the MacLean Lake Belt is underlain by a mixed assemblage of psammitic to pelitic metasediments, metagreywackes and varied hornblende

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

to amphibolitic gneisses which have been interpreted as metavolcanics, metavolcaniclastics and tuffaceous metasediments (Kirkland, 1959; Lewry, 1984).

The Central Metavolcanic Belt is intruded by a variety of ultramafic to felsic plutons, some of which are subvolcanic composite zoned bodies ranging from gabbro-diorite at the margins to granite cores. The flanking, mainly metasedimentary Crew Lake and MacLean Lake Belts are intruded by more homogeneous felsic plutons.

As the geology of most of the Waddy Lake area (North and South sheets) has been described (Harper, 1984), the lithological descriptions presented here will pertain mainly to the Tower Lake area and to the western and southeastern previously unmapped portions of the two Waddy Lake sheets. Although primary volcanic and sedimentary structures abound, the lack of good marker horizons and structural complexities makes it difficult to determine a coherent stratigraphy across the entire area. Additionally, interlayering and interdigitation of compositionally distinct but time equivalent units add to

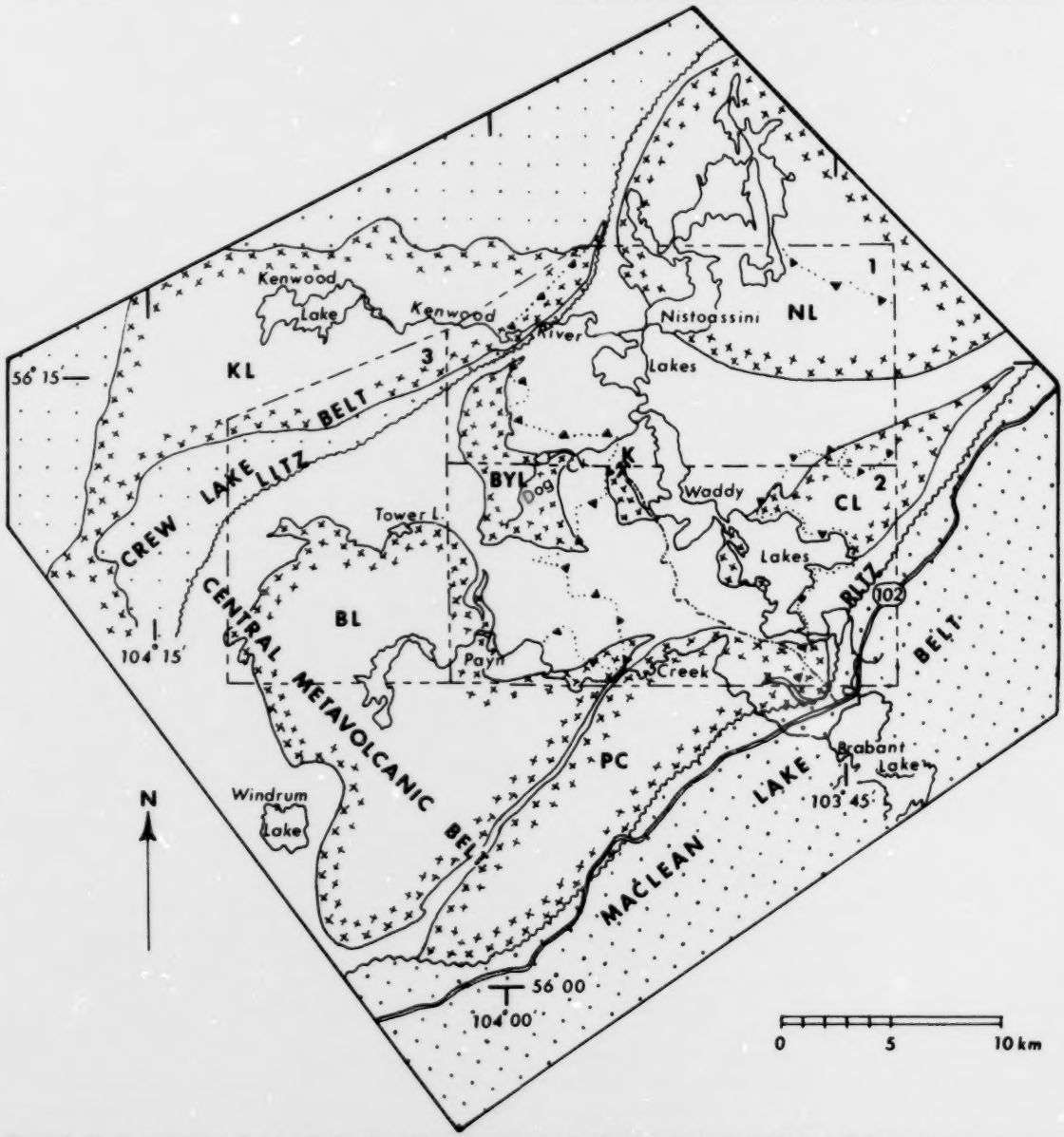

***Figure 1** - Geological sketch showing the location of the mapped areas (1, Waddy Lake North; 2, Waddy Lake South; 3, Tower Lake) with respect to the subdomains of the La Ronge Domain. Crosses indicate the major plutonic bodies (KL, Kenwood Lake; NL, Nistoassini Lake; CL, Contact Lake; BYL, Boundary Lake; PC, Payn Creek; BL, Brindson Lake Plutons). Major tectonic zones are LLTZ, Looney Lake and RLTZ, Redhill Lake tectonic zones. K, Komis gold deposit. Dotted line with solid triangles marks the limits of 1984 mapping.*

the complexity. Therefore the volcanic rock units will be described under broader headings of ultramafic, mafic, intermediate and felsic metavolcanics. Sedimentary rocks of the Waddy-Tower Lakes area can be broadly subdivided into two types, intravolcanic/volcanogenic and epiclastic. The intravolcanic/volcanogenic rocks are essentially restricted to the Central Metavolcanic Belt, whereas epiclastic types occur in all three belts. Epiclastic sedimentary rocks in the Waddy Lake area are largely confined to the Lower Sedimentary Rocks unit (unit S), comprising the Kenwood, Contact Lake, Lower Waddy Lake and Payn Creek sections (Harper, 1984). New field evidence and reallocation of the Kenwood section to the Crew Lake Belt necessitates dropping the term "Lower Sedimentary Rocks" as a unit name.

As all rocks of the area have been metamorphosed, the term 'meta' is deleted to avoid unnecessary repetition. Specific characteristics of the volcanic rocks (e.g., massive, amygdaloidal), where discernible in the field, are indicated by one or more suffixes on the accompanying maps.

Ultramafic Volcanics (Unit U)

Ultramafic volcanics are restricted to the southern end of Lower Waddy Lake and have not as yet been identified elsewhere in the Waddy-Tower Lakes area. The Lower Waddy Lake ultramafic to mafic assemblage includes high magnesium "komatiitic to basaltic-komatiitic- like" flows and pyroclastics with subordinate intercalated greywacke and pelitic sediments, and minor siliceous mixed-facies iron formation. This assemblage has been intruded by massive to layered, probably sub- or synvolcanic, pyroxenitic, peridotitic and possibly dunitic sills and plugs. A younger composite (mafic to felsic) pluton, the Redhill Lake Stock, and a number of still younger porphyritic quartz monzonite and granite pegmatite dykes and sills intrude the succession. The relationship between the Lower Waddy Lake ultramafic-mafic assemblage and the rest of the volcanic sequence is still uncertain because the contact between them is nowhere exposed. Nevertheless, this lithologically and chemically distinctive unit undoubtedly represents the oldest volcanic rocks in the area (Harper, 1984).

The **green magnesium-rich volcanics** (subunit Ugb) crop out mainly to the west of the Redhill Lake Stock and are very closely associated with the ultramafic sills and plugs, suggesting a close genetic link between them. In places they appear to grade into the less magnesian **black-weathering basaltic volcanics** (subunit Ubb) and also occur as rare lenses and pods (perhaps boudins) in subunit Ubb. Identifiable flows and pillowed flows are rare in both subunits. The dominant rock type of the black-weathering basalt is a delicately to thinly layered tuffaceous rock consisting of alternating mafic and felsic layers, typically less than 1 cm and exceptionally as much as 10 cm thick. Locally, the tuffaceous rocks are interlayered with and appear to grade laterally (to the northeast) into volcanogenic **greywacke and pelitic sediments** (subunit Usg). The sediments are typically rusty weathering, light to dark grey, fine to medium grained, equigranular, thinly layered and have a high mafic content (40 to 60 percent), reflecting their derivation from the adjacent volcanics. Garnet is present locally. The sedimentary interlayers range from a few tens of centimetres to more than 100 m thick along the southeastern margin of the northeasterly thinning wedge of black basaltic volcanics.

Also interlayered with the black basaltic volcanics are thin horizons, generally less than 0.5 m thick, of heavily iron-stained, coarse-grained (1 to 10 mm grain size), magnetite and/or pyrite pyrrhotite-garnet- amphibole-quartz rocks. These are interpreted as low-grade, mixed siliceous oxide-sulphide-silicate facies iron formation.

Mafic Volcanics (Unit B)

The mafic volcanic unit primarily includes all other basaltic rocks in the area. In the area between the Boundary Lake Pluton and Upper Waddy Lake and southwards to Payn Creek, rocks of basaltic composition comprise less than 10 percent of the exposed volcanosedimentary sequence. Basaltic rocks increase in importance however, along the east margin of the Brindson Lake Pluton and comprise up to 50 percent of the volcanosedimentary sequence in the Tower Lake area, where they consist of massive and pillowed flows with subordinate pyroclastics which are interlayered with flows and less pyroclastics of intermediate to felsic composition. A few thin flows are interlayered with the transitional volcanogenic sediments and epiclastic sediments of the Crew Lake Belt. The basalts are dark green to greenish-black on weathered and fresh surfaces, commonly very fine grained and are weakly to well foliated. Quartz and calcite occur as amygdules and where they have been leached the vesicularity of the original rock is well demonstrated. In places, particularly close to the margins of the plutons, coarse dark greenish-black hornblende porphyroblasts 1 to 5 mm across comprise up to 60 percent of the rock. Massive flow rocks appear to be most common, but the poor quality of exposure can mask the identity of other flow types.

Excellently preserved pillowed flows occur in a number of places. The pillows range from about 30 to 200 cm in length and up to 150 cm in width on outcrop surface. They are typically lobate with well-rounded upper surfaces and appear in most cases to be much more elongate in the down-dip direction. Chilled margins, vesicular (amygdaloidal) screens and well-developed interpillow selvages containing fragmental pillow debris are common features. Selvages are beige to dark green, very fine grained, tuffaceous to pelitic, and are generally 2 to 4 cm thick; a notable feature of the selvages is the almost ubiquitous occurrence of euhedral garnets 1 to 15 mm in diameter, which comprise up to 50 percent of the selvages. The few top determinations obtained from

the pillow lavas suggests the presence of a large, somewhat triangular shaped, synclinal or combined synclinal-anticlinal structure in the Tower-Hump Lakes region.

Intermediate Volcanics (Unit A)

Intermediate volcanics were identified in the field as andesite but probably include some overlap with basaltic and dacitic rocks. Although they are relatively abundant (40 to 50 percent) in the Waddy Lake area, they are less abundant to the west and constitute about 30 percent in the Tower Lake area. Porphyritic flows, flow breccias, ash, crystal and lapilli tuffs are the common varieties observed in the Tower Lake area. The andesites are typically greenish grey, aphanitic to very fine grained, finely foliated and are massive to very delicately laminated. Porphyritic flows and crystal tuffs contain 1 to 5 mm long plagioclase phenocrysts which rarely exceed 20 percent of the rock. Much of the fine ash tuff is probably waterlain and can be extremely difficult to distinguish from very fine grained sediments derived from rocks of equivalent composition. Lapilli tuffs contain recognizable mafic to felsic fragments which commonly do not exceed 1 cm length in the Tower Lake area.

Felsic Volcanics (Units D and R)

Felsic volcanics include rocks ranging from **dacite** (unit D) to **rhyolite** (unit R). As was found in the Waddy Lake area (Harper, 1984), rocks of this compositional range are far more abundant in the Tower Lake area than previously indicated (Miller, 1949), being most abundant in the vicinity of Kirk and Hump Lakes, between Centre and Partington Lakes, and southwest of Stingray Lake. Each of these felsic 'centres' contains associated exhalative sulphide-facies iron formation horizons.

Mapping in the western portion of the Waddy Lake South area further delineated the Earl Lake felsic volcanic sequence. This sequence consists predominantly of dacitic to rhyolitic pyroclastics (agglomerates to ash tuffs) with subordinate andesitic pyroclastics and intercalated andesitic to rhyolitic flows and porphyry dykes. The extensive pyroclastic accumulation indicates major explosive eruptive activity with fragments being coarsest in the east and generally finer to the west. The apparent thickness of the sequence is undoubtedly enhanced by folding, with the felsic rocks occupying the core of a synclinal structure.

Dacitic volcanics (Unit D) are light to dark grey and brownish grey on both fresh and weathered surfaces, aphanitic to very fine grained, finely foliated and range from finely laminated to massive and thick bedded. Pyroclastic rock types include ash, crystal, lithic and lapilli tuffs (or combinations thereof), tuff breccias and agglomerates. Flow rocks include massive, pillowed, porphyritic and flow breccias. The diversity indicates a range of submarine to subaerial volcanism, the former being most common in the vicinity of Hump Lake and the latter in the Earl Lake felsic sequence.

In the pyroclastic varieties, fragments are commonly of similar or more felsic composition than the matrix, whereas more mafic (andesitic) fragments are rare. The majority of fragments are less than 30 cm long, and rarely up to 1 m long. The original angularity of the fragments is commonly preserved despite a flattened appearance. This flattening may have occurred shorty after deposition (C.F. Fisher and Schmincke, 1984) rather than during a later tectonic episode. Feldspar phenocrysts, which are most common in the finer tuffs, range from 1 to 5 mm in size and generally comprise less than 20 percent of the rocks. Dacitic tuffs, minor coarse pyroclastics and porphyritic flows occur in the Partington-Centre Lakes felsic sequence. To the north, west and southwest of Hump Lake, dacitic ash tuffs are increasingly interlayered with and become indistinguishable from dark grey to black, very fine grained volcanogenic argillite and greywacke.

Well-preserved dacitic pillow lavas occur at Hump Lake and south of Stingray Lake. At Hump Lake they range from 30 cm to more than 1 m in length and up to 50 cm in thickness, in places displaying delicate concentric cooling fractures. Pillow selvages are typically 3 to 4 cm thick. South of Stingray Lake, well-rounded pillows from 30 cm to 100 cm across display thin chilled margins, delicate cooling fractures and interpillow spaces up to 30 cm across. The selvages here, like the nearby basaltic pillows, contain euhedral garnets up to 1 cm in diameter.

Massive porphyritic dacite flows and/or sills are common around Hump Lake. They contain up to 40 percent feldspar phenocrysts 1 to 5 mm across, and in a few places rare quartz phenocrysts occur. Porphyritic synvolcanic dacite dykes from a few tens of centimetres to 5 m thick are similar to these rocks, but are generally slightly coarser grained. They are most abundant in the vicinities of Centre, Narrow and Earl Lakes.

Rhyolitic and rhyodacitic volcanics (unit R and subunit Rd) are white, pink and light grey on fresh and weathered surfaces, aphanitic, finely laminated to massive, and commonly finely foliated. They include massive to blocky autobrecciated flows, ash tuffs to agglomerates, and quartz eye and/or feldspar porphyritic tuffs and small intrusive bodies. The present mapping indicates that rhyolitic and rhyodacitic volcanics are most abundant in the western portion of the Earl Lake felsic sequence (i.e., between Earl and Boundary Lakes and southwards to Payn Creek) and in the area between Centre and Partington Lakes. They also occur in the vicinities of Hump and Stingray Lakes, as isolated thin flows within the basaltic rocks north of Tower Lake, and in the areas west of Round Lake and southwest of Lower Nistoassini Lake.

In the triangle bounded by Earl Lake, Boundary Lake and Payn Creek, finely laminated to foliated rhyodacitic and

lesser rhyolitic tuffs occur with subordinate lapilli tuff and rare coarse pyroclastics. A few quartz-eye rhyolites of probable tuffaceous origin are also present. A number of pyritic zones with up to 10 percent pyrite occur in rhyodacitic tuffs and/or associated cherty exhalative sediments.

The Partington-Centre Lakes felsic sequence comprises, in addition to dacitic volcanics, predominantly rusty weathering, pyritic rhyodacitic tuffs and lapilli tuffs with subordinate rhyolitic lapilli tuff, quartz-eye rhyolite, argillite and cherty sulphide-facies iron formation. The quartz-eye rhyolites (subunit QER) are noteworthy in that they contain up to 30 percent quartz phenocrysts which average 5 mm diameter, and a few are as much as 10 mm long. About one-third of the quartz phenocrysts are blue.

At Hump Lake, rhyodacitic to rhyolitic tuffs and agglomerates are closely associated with a massive sulphide zone. A thicker sequence of similar rocks occurs east of Hump Lake along with porphyritic (feldspar) rhyodacite and interlayered rusty weathering pyritic argillites. Rare quartz-feldspar rhyolite porphyry intrusives occur north of Hump Lake.

Quartz-eye rhyolite (subunit QER), with or without accompanying feldspar phenocrysts, is most abundant in the area surrounding Round Lake and is an important unit southwest of Lower Nistoassini Lake. Distinctive blue quartz phenocrysts, 1 to 5 mm in diameter, comprise up to 30 percent of the Round Lake quartz-eye rhyolites. These rocks are probably genetically related to the blue quartz-bearing Boundary Lake Pluton and/or the Round Lake Stock. Southwest of Lower Nistoassini Lake, quartz-eye rhyolites with clear quartz grains form an integral part of a mafic to felsic extrusive-intrusive complex. This complex consists of basalt-andesite- dacite-rhyolite volcanics, interlayered argillites, and small syn-to subvolcanic sills and stocks which vary from diorite-granodiorite to quartz monzonite and quartz-feldspar rhyolite porphyries.

Sedimentary Rocks of the Central Metavolcanic Belt (Units S2 and S)

Intravolcanic/volcanogenic sediments (unit S2) include both clastic (argillite-greywacke and minor conglomerate) and chemical (iron formation, chert) sediments directly related to volcanic rocks and processes. They tend to be closely associated with felsic volcanic rocks and in places appear to be lateral equivalents of felsic pyroclastics. North of Partington Lake, along the western edge of the belt, the sediments are intercalated more with mafic to intermediate than felsic volcanics. Epiclastic sediments (unit S) include arkosic to semipelitic rocks with minor conglomerate, greywacke and argillite.

Interbedded argillite-greywacke (subunit S2ag) is the most abundant unit in the area. The rocks are light to dark grey on fresh and weathered surfaces but commonly show splotchy to intense iron staining depending upon the amount of disseminated iron sulphide present. Carbonaceous varieties are black, slaty to fissile and pyritic. The rocks are finely laminated to massive in appearance and generally very fine grained, but in places contain porphyroblasts of hornblende, biotite, garnet and staurolite 1 to 20 mm in size. Locally these rocks are interlayered with banded black carbonaceous chert or siliceous argillite alternating with iron sulphide layers.

Conglomerate (subunit S2c) is commonly associated with felsic volcanic sequences, such as at Hump Lake and the large quartz-eye rhyolite 'dome' west-southwest of Lower Nistoassini Lake. At Weedy Lake, conglomerate is associated with a predominantly mafic to intermediate volcanic sequence. The conglomerate typically occurs as relatively thin beds up to 2 m thick and is commonly clast supported and moderately well sorted. The clasts are subangular to rounded generally 1 to 2 cm in diameter but a few are more than 4 cm in size and consist dominantly of felsic volcanics and quartz, with lesser mafic to intermediate volcanics and rare intrusive rocks. The pale brown to green matrix varies from arenaceous to pelitic.

At Weedy Lake, a lens up to 40 m thick and at least 400 m long of generally polymictic conglomerate/breccia apparently underlies mafic pillowed flows which are sufficiently well preserved to indicate tops to the north. In general the conglomerate is represented by poorly sorted beds 1 to 5 m thick, which are both clast and matrix supported and consist of angular to rounded clasts. Clast size ranges from a few millimetres to 40 cm size boulders, and compositionally they consist of mafic to felsic volcanics and intermediate plutonic rocks very much like adjacent rock types. Mafic clasts weather preferentially, which produces a pitted weathered surface, and they tend to be more elongate and flattened, a feature which may be inherited from the original clast shape. Felsic volcanic clasts are both angular and well rounded, whereas intrusive rock clasts tend to be well rounded and show the least degree of flattening. The matrix is a pinkish, locally epidotic, granular feldspathic arenite.

When considered as an intravolcanic clastic sediment, the Weedy Lake conglomerate/breccia lens indicates the existence of contemporaneous subaerially exposed land masses in which high level intrusive rocks were exposed relatively early in the history of the volcanic arc. The conglomerate stratigraphically underlies mafic pillowed lavas, indicating a change from subaerial to sub-aqueous conditions. Alternatively but less likely, if this same clastic lens is considered to be a basal conglomerate member of the Contact Lake epiclastic sediments to the south, that would imply an unconformable relationship with the pillowed lavas and therefore require tops to be facing in opposite directions. This would in turn necessitate some form of deformation (tilting, faulting, folding) prior to deposition of the conglomerate. Interpretation is hampered because bedding and other primary structures to aid in top determinations are obscure and the three

dimensional aspect of the conglomerate-volcanic contact is not observable.

Iron formation (subunit S2F) of the Central Metavolcanic Belt includes massive pyrite and/or pyrrhotite, mixed cherty sulphide-oxide-silicate-facies iron formations interlayered with bedded pyritic, carbonaceous, siliceous argillite (possibly black chert) and white chert. Sulphide-facies iron formations predominate in the Tower Lake area; they are generally poorly exposed but their presence is indicated by heavy gossanous soils and small sulphurous-smelling ponds underlain by bog iron ore. In the vicinity of Kirk and Hump Lakes, one sulphide horizon outlines a fold which closes to the northeast. Several prominent zones along the limbs of this structure were described by Harper (1983). Banded cherty oxide-silicate-facies iron formation occuring about 1 km west of Kirk Lake is characterized by alternating white sugary-textured chert layers, and dark green magnetite-bearing silicate layers which consist of amphibole, chlorite and garnet. A little pyrite and pyrrhotite is also present. Soft sediment deformation of this iron formation is believed responsible for the brecciated character of the chert layers. This type of iron formation is very similar to gold-bearing iron formations present at the Twin Zone (Harper, 1984).

The epiclastic rocks (unit S) are described by Harper (1984); however, some additional comments stemming from the recent mapping will be made here. Re-examination and further mapping of the Lower Waddy Lake section revealed an unconformable contact beween the ultramafic-mafic assemblage and the sediments. Polymictic conglomerate (subunit Sc), which occurs locally along the contact, contains clasts of the adjacent volcanics as well as intrusive rock clasts resembling local porphyritic quartz monzonite dykes/sills and different phases of the Redhill Lake Stock. The clasts are generally elongate and rounded but poorly sorted, ranging from a few millimetres to 30 cm across, and are encased in a pinkish, granular arkosic matrix. Locally the matrix is strongly epidotized. Elsewhere along the contact the volcanics are overlain by psammitic to semipelitic rocks in which the mafic mineral (biotite, hornblende) content decreases over several metres away from the volcanics. The **arkosic-psammitic rocks** (subunit Sa) which dominate the Lower Waddy Lake section are progressively more deformed towards the Contact Lake pluton. Isoclinal folds, imbricate tensional fracturing of more resistant layers, stronger foliation and lineation and discrete epidotized shear planes subparallel to bedding are indicators of this deformation, and are believed to result from a major fault/shear zone coincident with and/or subparallel to the intrusive-sediment contact.

The relationship between the Lower Waddy Lake section and the lithologically equivalent Contact Lake section with the rest of the volcanic sequence is still uncertain, as a contact between them is nowhere exposed. In the Contact Lake section, the psammitic (arkosic) to semipelitic (minor greywacke and argillite) rocks structurally underlie the volcanics. Way-up evidence suggests they also underlie them stratigraphically. However, a prominent topographic and airphoto lineament separating the two units strongly suggests they are in fault contact. Such a fault may represent the faulted limb of a syncline within which the sedimentary rocks lie. As mentioned above, the conglomerate at Weedy Lake could possibly be a remnant of a basal conglomerate. Thus these sedimentary rocks may be younger than the rest of the volcanic sequence.

Sedimentary Rocks of the Crew Lake Belt (Unit C)

The transition from the Central Metavolanic Belt into the Crew Lake Belt varies from sharp to imperceptible across the Looney Lake tectonic zone. The sedimentary rocks include a conglomerate-agglomerate sequence which gives way to an argillite-greywacke assemblage to the southwest, while both progress into pelitic, semipelitic, psammitic rocks to the west. The transitional nature of the eastern margin of the Crew Lake Belt is also indicated by the interlayering of the sedimentary rocks with distal equivalents of mafic to felsic volcanics of the Central Metavolcanic Belt.

The **conglomerate-agglomerate sequence** (subunit Ca) underlies an elongate area 8 km long by up to 1 km wide. The width represents the approximate thickness of the unit, although repetition by faulting is a possibility. In general these rocks are pink to light grey on fresh and weathered surfaces, and locally have a pale yellow-green colour due to epidote replacement. Although dominantly clast-supported, the amount of matrix, typically a fine-grained feldspathic material, increases to the northwest, as do interlayers of fine-grained, finely laminated, pink feldspathic arenite. Clasts up to 100 cm across occur along the southeastern edge but are generally smaller to the northwest. Felsic volcanic clasts/fragments (rhyolite, dacific tuffs, porphyritic dacite flow) dominate (up to 95 percent) in the northeast. Intrusive rock clasts (diorite to granite) increase in abundance (up to 20 percent) towards the southwest. Mafic volcanic clasts are rare, and in the Looney Lake area a few large well-rounded boulders (up to 50 cm in diameter) resemble the leucogranite phase of the nearby Boundary Lake Pluton. The shapes of the clasts vary from extremely elongate, with angular to rounded corners, to ovoid and well rounded. The degree of flattening decreases and roundness increases to the southwest in response to the decreasing strain in that direction.

The unit seems to be more pyroclastic at the northeast end, where it appears to consist of felsic agglomerate and debris flow breccias as well as interlayered conglomerate and feldspathic arenite. The pyroclastic appearance becomes less pronounced to the southwest.

The **argillite-greywacke assemblage** (subunit Cb) which is essentially the same as in the Central Metavolcanic Belt, appears to grade into the more pelitic-psammitic rocks to the west.

Pelitic, psammopelitic and psammitic rocks (subunit Cc) occur in the westernmost part of the sedimentary portion of the Crew Lake Belt where they are interlayered on a centimetre to metre or greater scale. The rocks are finely laminated to thinly bedded (to 10 cm thick) and fine to coarse grained, the coarseness increasing to the northwest as the metamorphic grade increases and the contact with the Kenwood Lake Pluton is approached. Pelitic varieties are brownish to grey weathering whereas the psammopelitic rocks are light grey. Quartz is more abundant (30 to 60 percent) in psammopelitic varieties and biotite increases from 5 percent in the psammitic to 20 percent or more in the pelitic varieties. Within 100 m of the contact with the Kenwood Lake Pluton, granitic neosomal stringers, pods and layers are progressively more abundant, as are subparallel intrusive granodiorite to diorite sheets.

Rocks of the MacLean Lake Belt (Units MLa,MLb, MLc and MLd)

All rocks of the MacLean Lake Belt are gneissic and lie east of a major north-northeast- to northeast-trending topographic lineament, which marks a fault trace separating the MacLean Lake from the Central Metavolcanic Belt. The exception to this is a small enclave along the southern margin of the Payn Creek Pluton. Four units are identified: an interlayered arkosic, semi-pelitic, pelitic assemblage (unit MLa), biotite and biotite-hornblende quartzofeldspathic gneisses (unit MLb), calc-silicate gneiss (unit MLc) and amphibolitic-dioritic gneiss (unit MLd). The last three subunits crop out east of Highway 102, and are more abundant to the southeast (Kirkland, 1959; Johnston, 1969).

The **arkose-psammopelite-pelite** unit, which crops out in a northeast-trending zone, 2 to 2.5 km wide, southeast of the Redhill Lake Tectonic Zone, is probably equivalent to the McLennan Group (Lewry, 1983, Thomas, 1984). The rocks are generally light grey, pinkish-grey, to grey on fresh and weathered surfaces, coarse grained (1 to 2 mm grain size), equigranular and well foliated. White, very coarse grained, granitic neosomal layers, lenses and pods up to 10 cm thick locally comprise up to 30 percent of the rocks. Interlayering produces a colour-banded effect on a 5 to 10 cm and more rarely 1 m scale. Extensive recrystallization of the arkosic varieties has locally produced a granitoid-textured rock in which the supracrustal parentage is indicated by wispy biotitic remnants and by gradation into colour-banded well-layered varieties.

Biotite and biotite-hornblende quartzofeldspathic gneisses (unit MLb) underlie the extreme southeastern corner of the Waddy Lake area (south sheet). They are grey to dark grey on fresh and weathered surface, coarse grained, poorly to well layered, and strongly foliated. Some biotite-rich (30 to 40 percent) varieties are rusty weathering, fissile and contain a few percent disseminated pyrite. The biotite-hornblende quartzofeldspathic gneiss resembles granodiorite compositionally, has a massive appearance and contains 10 to 30 percent biotite and hornblende in about equal proportions. A few tiny garnets (0.5 mm in diameter) are present locally.

Interlayered with the biotite-hornblende quartzofeldspathic gneiss is a 6 to 10 m thick horizon of **calc-silicate gneiss** (unit MLc) which is greenish grey, coarse grained, thinly layered (1 to 10 cm thick) and well foliated. Diopside, quartz and plagioclase are the principal components with minor aggregates of red-brown garnets 0.5 mm in size.

Amphibolite-dioritic gneiss (unit MLd) occurs in two separate zones of 20 and up to 100 m thickness. The rocks are dark grey to black, coarse grained (1 to 4 mm), strongly foliated and composed of 40 to 60 percent hornblende with complimentary plagioclase and locally a few percent biotite. These rocks resemble diorite but may be strongly metamorphosed basalts. The thicker of the two zones contains several 30 to 40 cm thick layers or dykes of very coarse grained (3 to 10 mm across) hornblendite (metagabbro?) which is highly disrupted, boudinaged and folded.

Ultramafic Intrusive Rocks (Units Up and Px)

Except for a few small pyroxenite bodies (unit Px) located west and north of Upper Waddy Lake, ultramafic intrusives (unit Up) are concentrated in the Lower Waddy Lake area where massive and layered pyroxenitic, peridotitic and possibly dunitic sills and small stocks intrude ultramafic volcanics and associated sedimentary rocks. A general description of the Lower Waddy Lake ultramafic intrusives (unit Up) was given by Harper (1984). New evidence suggests that, although some of the peridotitic rocks of subunit Upd may be flows, most are believed to be synvolcanic sills. Flow rocks are suggested by curvilinear features which appear to outline pillows; however, the same patterns can be generated by fracturing, leaving their interpretation open to speculation. Of greater importance is the observation of large- and small-scale primary intrusive layering in several of the bodies. The gross layering in one such body (subunit Upl) ranges from 20 to 200 cm thick with serpentine pseudomorphs after olivine-rich, olivine-pyroxene or pyroxene-rich layers; whether plagioclase was originally present is difficult to determine. Fine- and coarse-grained varieties also occur, ranging from 1 to 8 mm in grain size. Small-scale rhythmic layering 3 to 6 mm thick is indicated by alternating light and dark layers of serpentine pseudomorphs of olivine-pyroxene and/or pyroxene-plagioclase.

Two stocks are identified; one crops out partly on Red Hill and the other across the southern end of Lower Waddy Lake. The **Red Hill body** is unique in that it consists almost entirely of fine- to coarse-grained (0.1 to 10 cm), brown to red-brown weathering (dark grey to bluish grey on fresh surfaces), massive serpentine (antigorite?) pseudomorphic after pyroxene, olivine or intergrowths of

both. Magnetite comprises 2 to 3 percent of the rock as 1 to 3 mm size disseminations and in late anastomosing white-weathering fibrous serpentine-magnetite veinlets. The entire body appears to have been at one time coarse-grained antigorite (4 to 10 cm in size), suggesting that its precursor must also have been very coarse grained. Parts of the body have been progressively recrystallized to finer grain sizes as a result of shearing or fracturing. The higher the density of fractures in a given area the broader the zone of finer recrystallization. The tectonic derivation of this essentially monomineralic body is still open to question, but it was very probably emplaced as a coarse crystal mush (Watters, pers. comm., 1985).

The **Lower Waddy Lake body** is relatively poorly exposed on a number of small islands and headlands across Lower Waddy Lake and is characterized by a wide array of colours, grain sizes, textures, compositions and degree of later serpentinization. Coarse crystals, probably of antigorite (up to 2 cm across) pseudomorphing olivine and/or pyroxene, are also present locally. On one island a series of what appear to be monomineralic layers 2 to 10 cm thick may have resulted from intrusion of closely spaced ultramafic dykes. Compositionally the body appears to range from pyroxenite to peridotite and possibly dunite.

A small **pyroxenite** (unit Px) body, located north of Dog Lake, is pale green on weathered and fresh surfaces, poorly foliated, medium grained (1 to 2 mm) and soft. It appears to be composed of talc, tremolite and chlorite.

Mafic Intrusive Rocks (Unit Gb)

Gabbroic rocks (unit Gb) occur in several small stocks and as border phases of several of the larger plutons. The rocks are commonly dark green to black, coarse grained (3 to 10 mm) and massive or weakly foliated. The **Tower Lake Stock** has leucocratic (subunit Gba), mesocratic (subunit Gbb) and melanocratic (subunit Gbc) varieties and is locally dioritic (subunit Gbd). Hornblende ranges from 30 to 95 percent of the rock, with plagioclase the other major constituent. Pyrite is a common accessory and chalcopyrite is present locally. Xenolithic blocks of metabasalt are sporadically distributed through the body.

Another body occurs in granite of the Brindson Lake Pluton about 1.5 km east of Loppe Lake. This body, which is about 1 km across at its northern end has narrow dioritic (subunit Gbd) margins but is predominantly a massive coarse-grained melanocratic gabbro (subunit Gbc) containing 80 to 95 percent hornblende. Leucogabbro or anorthositic layers or pods containing 30 percent or less amphibole are present locally. The massive nature of this body makes it appear to be intrusive into the Brindson Lake Pluton.

A small body of anorthositic gabbro (subunit Gba) occurs along the southern margin of the Contact Lake Pluton and has been intruded by granodiorite of the pluton. The gabbro is characterized by up to 50 volume percent pseudomorphed plagioclase phenocrysts, 1 to 3 cm long and up to 1 cm thick, which show random to preferred orientation in a primary cumulate texture. These phenocrysts have been completely recrystallized to an equigranular aggregate of plagioclase grains less than 1 mm in size.

Intermediate Intrusive Rocks

A number of **diorite** (unit Di) **quartz diorite** (unit QDi), **monzonite** (unit Mz), quartz monzonite (unit QMz) and **granodiorite** (unit Gd) sills and small stocks occur throughout the area. Although Byers (1948) mapped a small diorite stock at the north end of Clear Lake only dioritic boulders were observed in that area during the present mapping. A number of microdioritic sills occurring in the volcanosedimentary sequence are dark greenish grey, fine grained (1 mm grain size), massive and are in places indistinguishable from phyric andesite flows. Several small diorite-granodiorite stocks, which occur west of Lower Nistoassini Lake, may represent part of a vent complex. Another small quartz diorite body lying in the Crew Lake Belt west of Kirk Lake is more extensive than indicated by Miller (1949). It resembles diorite of the Kenwood Lake Pluton.

Intermediate to Felsic Intrusive Rocks (Units G1, G2, and G3)

Intrusive stocks and larger plutons predominantly of felsic composition underlie 30 to 40 percent of the Waddy Tower Lakes area, and are subdivided into three groups.

Group 1 zoned intermediate to felsic intrusive rocks (unit G1) include the Brindson Lake, Boundary Lake, Nistoassini Lake and Redhill Lake plutons. These plutons are believed to be early, subvolcanic differentiated bodies that developed coeval with the evolving volcanic arc. The zonation typically ranges from **gabbro** (subunit G1a), **diorite, quartz diorite, monzodiorite** (subunit G1b) in the marginal zone to **monzonite-granodiorite** (subunit G1c) in an intermediate zone to **quartz monzonite** (subunit G1d) and **granite** (subunit G1e) and locally **leucogranite** (subunit G1f) in the core. The different components are commonly asymmetric in their distribution and the transition from one zone to the next varies from gradational to sharp, indicating that both differentiation of the magma as well as discrete intrusive pulses were important factors governing emplacement of the plutons. Other mafic to intermediate intrusions in the area, such as the Tower Lake, Dog Creek and Sonya Lake stocks were probably emplaced about the same time as the marginal zones of these plutons. It is possible that the leucogranites are the subvolcanic intrusive equivalent of late felsic pyroclastic volcanism.

The **Brindson Lake Pluton** has a broad gabbroic-dioritic marginal zone along its northern and eastern flanks and grades southward and eastward into a monzonite-

granodiorite zone and then into a hornblende-biotite granite zone which continues to the western contact. A diagnostic feature of the diorite, quartz diorite, monzodiorite and monzonite of the marginal zone is a pale yellow-green coloration of plagioclase, probably the result of deuteric saussuritic alteration. The core of the granite zone is characterized by porphyritic biotite-hornblende granite (subunit G1g) with phenocrysts of biotite up to 5 mm across and hornblende up to 1 cm long together comprising 20 to 25 percent of the rock. Dykes up to 1 m wide of aplite cut the granite and are possibly related to the emplacement of leucogranite. Several large mafic metavolcanic and metasedimentary roof pendants also occur in the granite zone. The metasedimentary remnants are rusty weathering, gneissic psammitic to pelitic rocks which most closely resemble the psammitic-pelitic rocks (subunit Cc) of the Crew Lake Belt.

The **Boundary Lake Pluton** is distinctive because all zones except the gabbro-diorite zone contain blue quartz phenocrysts 1 to 5 mm in diameter, which comprise from 5 to 30 percent of the rocks. Zonation is well developed but asymmetric, with the gabbro-diorite zone only occurring on the eastern side. Like the Brindson Lake Pluton, yellow-green coloration of plagioclase is nearly ubiquitous in diorite, quartz-diorite and monzonite. A central leucogranite zone appears to be discordant to the zoned pattern, cutting across the pluton in a north-south direction and perhaps even offsetting the earlier zoned portion. Aplite veins and dykes up to 50 cm wide intrude granite and granodiorite but were not observed intruding the leucogranite core.

The **Redhill Lake Stock** exhibits a north-south gradation of diorite-granodiorite-quartz monzonite. The quartz monzonite is intruded by northeast-trending leucogranite pegmatite dykes. The mafic nature of this stock may be partly due to contamination and assimilation of the surrounding ultramafic-mafic volcanic assemblage. A striking feature of this body is the numerous finger-like apophyses which extend eastward into the enclosing volcanic rocks.

The **Nistoosini Lake Pluton** was described by Harper (1984) and no additional investigations of the pluton were made in 1985.

Group 2 homogeneous granitic intrusive rocks (unit G2) include the Payn Creek, Contact Lake and Kenwood Lake plutons, which are believed to be late subvolcanic to early syntectonic and emplaced at a higher level than group 1 intrusions. These plutons are characterized by a generally narrow, discontinuous and locally xenolith-rich marginal zone which is more mafic than the bulk of the pluton. The marginal zone varies from diorite (subunit G2a) to granodiorite (subunit G2b); these two subunits appear to grade from one to another and into granite (subunit G2c) by the progressive reduction of mafic minerals and corresponding increase of quartz and potassium feldspar. Changes within the granitic rocks amount to a gradual decrease in the mafic content and a corresponding weakening of the planar fabric towards the centre. These plutons have well-developed large-scale curvilinear internal structural patterns.

The **Payn Creek and Contact Lake Plutons** were described by Harper (1984). New evidence indicates that the eastern termination of the Payn Creek Pluton has a discontinuous diorite and granodiorite margin which has been intruded by a number of leucogranite pegmatite dykes. This part of the pluton also appears to have been involved in regional folding with the surrounding metavolcanic sequence.

The **Kenwood Lake Pluton** appears to fit into this group because of the large-scale internal curvilinear patterns observed in aerial photographs. This pluton has been described previously as granite by Byers (1948) and Miller (1949) and diorite by Gracie (1965, 1966). Miller recognized a gradation from granite to diorite towards the southern margin. The present mapping shows that a narrow discontinuous dioritic and/or granodioritic border, characteristic of the Group 2 plutons, exists along this southern margin. Beyond the marginal zone the rocks are progressively more homogeneous and granitic.

Group 3 quartz-rich leucocratic granitic intrusive rocks (unit G3) include the Round Lake, Upper Waddy Lake and Kidney Lake stocks, as well as a number of smaller stocks in the Waddy Lake area (Harper, 1984); however, no such stocks were encountered in the Tower Lake area. These high-level intrusive bodies are probably syn- to late syntectonic, but possibly were coeval with emplacement of leucogranites of Group 1 plutons (for example, Boundary Lake Pluton). Many of these small stocks have distinctive pressure shadow regions and discontinuous pyritic, highly fractured, hornfelsic margins that locally contain quartz veining and accompanying gold mineralization (e.g., Round Lake and Kidney Lake Stocks).

Granite pegmatite (unit P) is most common in the southeast corner of the Lower Waddy Lake area, intruding all the rock types and occurring in dykes ranging from less than 1 m to as much as 60 m thick and extending as much as 1000 m along strike. Two types, tourmaline-bearing (subunit Pt) and garnet-muscovite-bearing (subunit Pgm), were identified previously (Harper, 1984). Further investigation revealed that both tourmaline and garnet occur together in some of the dykes. Rare blue to blue-green crystals of apatite up to 5 mm long and yellow-brown beryl, up to 2 cm long were observed in a few places. Feldspar crystals up to 150 cm across are present in the large north trending dyke which crops out on the eastern shore of Lower Waddy Lake. The pegmatites which intrude the Redhill Lake Stock and extend up to 2 km eastwards, are characterized by a gradation, from south to north, from a fine- to coarse-grained (1 to 3 mm grain size) leucogranite into a very coarse pegmatite (with crystals up to 30 to 40 cm) and locally containing muscovite, garnet, and tourmaline. The

north margin of the dykes is still pegmatite but the grain size averages less than 5 cm.

Mafic to intermediate dykes (Unit M), which are dark green to greenish black, aphanitic to very fine grained, and from 0.2 to 3m thick, are most commonly observed within mafic to intermediate volcanics, but also intrude felsic volcanics and sedimentary rocks. Many of these dykes are probably synvolcanic, but others are clearly the youngest magmatic event in the area. The greatest concentration of mafic dykes is in the Brindson Lake Pluton in the vicinity of Two Vulture Lake, where they intrude diorite and gabbro and also cut rusty weathering quartz veins. The dominant trend of the dykes is east-northeast, subparallel to a topographic lineament interpreted as a fault. A second minor set trends northwest to north-northwest, subparallel to fractures of that trend. Intermediate dykes having northeast and northwest trends are common in the easternmost part of Loppe Lake. This setting of mafic dykes and associated quartz veins within a composite pluton is similar to the Star Lake setting, and is enticing as an exploration target.

A single 30 cm wide 'lamprophyric' dyke containing 20 percent hornblende phenocrysts 1 to 3 mm long intrudes the gabbroic body 1500 m east of Loppe Lake.

Structure

The Waddy-Tower Lakes area has undergone polyphase deformation and is characterized by inhomogeneous strain. Primary features helpful in determining tops and indicating major folds include graded and cross bedding, scour-and-fill and slump structures, flow contacts, flow top breccias and pillow lavas. Unfortunately their distribution is inadequate for a more precise stratigraphic and structural picture.

Throughout most of the area, a finely developed tectonic foliation (S_1) parallels the original bedding and volcanic layering (S_0). The earliest fold structures (D_1) display a variety of axial traces, plunges and styles including isoclinal, arcuate and triangular patterns which are closely related to the size, shape and proximity to plutonic bodies. A series of anticlines and synclines occurs along the protrusions and embayments of the various plutons, and merge into larger regional synformal structures. This early deformation seems to be largely controlled by complementary sinking of the volcanosedimentary pile and the rise of various plutonic bodies. The triangular folds, which resemble large-scale pressure shadows, result from the intersection of paired arcuate and radial axial surfaces. The D1 foldup was accompanied by an early episode of faulting tending to parallel the intrusive margins (e.g., Byers Fault).

A later regional **northwest-southeast** compressional deformation (D_2) manifests itself as small-scale northeast-trending crenulation and kink folds, boudin necks and a locally developed subvertical axial planar cleavage and weak penetrative foliation (S_2). Possibly also related to this period of deformation are major, generally northeast-trending tectonic zones such as the Looney Lake and Redhill Lake tectonic zones. Some of these structures have been interpreted as possible thrust zones (Lewry, 1983). They are characterized by strong penetrative foliation, submylonitic textures, well-developed lineations, extensional fabrics and increased incidence of small-scale folding which probably reflects large-scale drag folding. The Looney Lake tectonic zone is distinctive in that the volcanosedimentary sequence is more tightly folded nearer the major lineament where the folds are abruptly truncated.

A period of late brittle fracturing, faulting and shearing was widespread and probably caused reactivation and movement along earlier formed faults. Although of variable attitude, two general trends appear to dominate, north-south and east-west.

Metamorphism

The regional metamorphic grade is upper greenschist to lower amphibolite facies. The grade generally increases towards the margins of the volcanosedimentary complex and is noticeably higher (upper amphibolite) in the flanking metasedimentary belts. Metamorphic grade also increases towards the margins of many of the plutons and hornfelsic aureoles are preserved around some stocks.

Diagnostic minerals of the upper greenschist-lower amphibolite facies transition include chlorite, actinolite, biotite, blue-green hornblende, garnet and staurolite. The grade in the Tower Lake area appears to be slightly higher than throughout most of the Waddy Lake area. Staurolite was found only at Hump Lake.

Lithogeochemistry

The lithogeochemical program initiated in 1984 was continued in 1985 with a large number of samples collected from the ultramafic-mafic assemblage in Lower Waddy Lake. Sample suites to characterize Group 1 and 2 intrusives were collected from the Boundary Lake and Contact Lake Plutons. Several volcanic rock types and pyritic felsic tuffs were also sampled. Results from this year's program are not yet available.

Preliminary results from the 1984 program were presented by Watters (1984) and further elaborated upon by Harper, Thomas and Watters (1985). The highlights of the 1984 programs are summarized briefly:

1) The volcanic rocks display chemical characteristics which are consistent with previous studies (Watters, 1981) on La Ronge Domain volcanics and support the idea of a volcanic arc origin for the Central Metavolcanic Belt.

2) The volcanics are dominantly sub-alkaline and show a continuum of rock types from basalt to rhyolite.

3) Jensen cation plots indicate the dominantly calc-alkaline to less well developed tholeiitic character of the volcanics, and a few samples from the southern end of Lower Waddy Lake display komatiitic to basaltic-komatiitic affinities.

4) The calc-alkaline trend displayed by the mafic to felsic plutons, similar to that of the volcanics, supports the idea that they are largely coeval with the evolving volcanic arc.

5) The volcanics have high alumina and low titanium contents, characteristic of arc volcanics.

Economic Geology

The economic geology of the Waddy Lake area was described by Harper (1984); therefore, this discussion will be restricted to the Tower Lake area. McMurchy (1937) reported that limited prospecting had been carried out in the region as early as 1928 and that several claims were staked in 1936 about a mineralized quartz prospect reported to contain sulphides and gold values. He also described a major sulphide zone, but unfortunately did not give the location of either occurrence.

The Consolidated Mining and Smelting Company of Canada Ltd. launched a major gold exploration program in 1944 which resulted in the discovery of a number of gold showings south of the present area (Coombe, 1984). In 1949, E.P. Partridge discovered the Kaslo occurrence on the north shore of Narrow Lake. The dramatic rise in the price of gold in the Seventies prompted the present resurgence of exploration activity and re-examination of all the known gold occurrences in the Tower Lake area, and hopefully will lead to new discoveries.

Sulphide Mineralization

Some of the sulphide occurrences are described by Miller (1949), Beck (1959) and Harper (1983). The mineralization consists of disseminated, massive and banded pyrite and pyrrhotite, and minor disseminated chalcopyrite and sphalerite. Drilling of many of the EM conductors revealed that most are caused by barren sulphide mineralization in zones up to 60 m thick. Assays indicate only minor values for copper, zinc, nickel, gold and silver (Assessment Files 74A01-NE-0002, 0003 and 0031)[1]. Small amounts of disseminated chalcopyrite occur in gabbro of the Tower Lake Stock.

Gold Mineralization

The presently known gold occurrences of the Tower Lake area are closely associated with the westerly-trending Byers Fault. Occurrences are located at Centre, Narrow and Tower Lakes, and typically occur within or adjacent to quartz veins within sheared mafic to felsic volcanics and/or mafic to intermediate intrusive rocks of the Brindson Lake Pluton (Coombe, 1984; Assessment Files 74A-01-0001, 0004, 0008, 0014). A little visible gold is commonly present and the veins typically contain disseminated pyrite, accompanied locally by chalcopyrite, sphalerite, galena and bornite. Wall rock alteration consists of chloritization, silicification and, at the Tower East occurrence, calcite. The Tower East occurrence has drill-indicated reserves of 400,000 tons with an average grade of 0.12 oz./ton (The Prospect, v1, no1, p1-2).

Minor gold showings exist in the area between Centre and Partington Lakes and along the western margin of the Brindson Lake Pluton, 2 km west of Brindson Lake. The former showing, referred to as the Narrow Lake occurrence (Miller, 1949; Beck, 1959), consists of pyritic quartz stringers in rhyolite porphyry. Barren sulphide mineralization in this general area contains trace amounts of gold, silver and copper (Assessment File 74A01-0014). The other occurrence, known as Exit Lake ENE (Coombe, 1984), consists of a narrow pyritic quartz vein with low gold values in volcanics adjacent to and in a hybridized contact zone of the Brindson Lake Pluton (Assessment File 74A01-0013).

The Tower Lake area has good potential for further gold discoveries. There are numerous untested shear systems adjacent to and within the various plutons and smaller stocks. Mixed oxide silicate±sulphide-facies iron formation, rhyolite porphyries, and felsic volcanic-sediment contacts all represent potential targets for gold exploration. Pyritic rhyodacitic-rhyolitic tuffs and/or cherty tuffs may also be of economic significance with respect to both gold and base metals in view of the Cu-Pb-Ag-Au occurrence in similar rocks immediately west of Earl Lake.

[1]Saskatchewan Energy and Mines, Regina.

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Geological Mapping, Roundish-Bervin Lakes Area (part of NTS 73P-15 and -16)

by D.J. Thomas

Thomas, D.J. (1985): Geological mapping, Roundish - Bervin Lakes area (part of NTS 73P-15 and -16); *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Geological mapping at 1:20,000 scale, which commenced in 1984 in the Star Lake area (Thomas 1984), was continued to the southwest during July and August 1985. The overall objective of the project is to upgrade the geological data base for the southern portion of the Central Metavolcanic Belt of the La Ronge Domain. One of the primary aims of the project is to identify whether a fundamental geological difference exists between the northern part of the belt (i.e., Waddy Lake area), where exploration work has identified a significant number of gold occurrences, and the southern portion where noticeably fewer occurrences are reported. Three main objectives are being focussed on:

1) Detailed documentation of the petrological, geochemical and stratigraphic characteristics of the volcanic deposits;

2) Examination of acid to basic intrusive rocks in order to establish their relation to volcanism and tectonism, as well as their potential as hosts for base and precious metals;

3) Examination of geological features characterizing gold occurrences at Star and Mallard Lakes to establish whether similar features exist elsewhere in the southern part of the belt.

The area investigated covers approximately 340 km^2 and lies within NTS sheet areas 73P-15 and -16. The centre of the area is about 96 km northeast of La Ronge and 30 km north-northeast of Missinipe. Highway 102, an all weather gravel road, extends the entire length of the eastern portion of the study area. The western and central portions of the area are readily accessible by float equipped aircraft. Lakes with good shoreline exposure include McLennan, Bervin, Tate, Gibbons and Laroque. A forest fire in 1984 between Ismond and Bervin Lakes provided 'clean' bedrock exposures which greatly aided in the interpretation.

Previous geological mapping of the area includes portions of surveys by McLarty (1935), Pearson and Froese (1959), Morris (1961) and Lewry (1983). The area is also covered by the following published geophysical maps:

1) 1:63,360 scale Federal-Provincial aeromagnetic series map 4790G (Forbes Lake, 73P-15) and 4791G (Settee Lake, 73P-16);
2) 1:250,000 scale Federal-Provincial aeromagnetic series map 8190G (Lac La Ronge, 73-P).

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Regional Background

The area is underlain by Precambrian rocks covered by a thin veneer of glacially deposited Pleistocene tills.

The Roundish-Bervin Lakes map area lies in the Central Metavolcanic Belt of the La Ronge Domain. The belt comprises metavolcanic and minor metasedimentary assemblages intruded by uniform to complex acid to basic plutons. To the east, feldspathic meta-arenites of the McLennan Group structurally underlie the Central Metavolcanic Belt. The Crew Lake Belt comprises mainly relatively monotonous psammitic and psammopelitic rocks ('metagreywackes') and minor pelitic rocks (metashales), and structurally and stratigraphically overlies the volcanic rocks to the west. The transition between these two belts has been in part disrupted by the emplacement of plutons and by later shearing.

A postulated sequence of geologic events is given in Table 1. Age determinations by the U-Pb (zircon) method for volcanic and plutonic rocks in the Central Metavolcanic Belt indicate that major igneous activity occurred around 1866 to 1910 Ma (Van Schmus et al., 1985). Peak regional metamorphism related to Hudsonian thermotectonism is thought to have affected rocks before 1850 Ma (Van Schmus et al., 1985), although a thermal resetting of whole rock and mineral Rb-Sr ages may have occurred around 1740 Ma, towards the conclusion of regional metamorphism (Macdonald pers. comm.).

Metavolcanic Rocks

The central portion of the map area is underlain by a northeast-trending belt of **metavolcanic rocks** of dominantly mafic to intermediate composition with less abundant felsic metavolcanic rocks. The metavolcanic rocks underlie an area approximately 4 km wide in the north and 9.5 km wide in the south (Fig. 1). Although regional metamorphism and tectonism have altered the primary mineralogy and fabric of the rocks, many original textural and structural volcanic features have been preserved. Pyroclastic and flow deposits are present in approximately equal amounts across the map area, although in detail a number of zones may be distinguished:

1) A northeast trending belt of dominantly mafic to intermediate flows with several narrow felsic flow horizons underlies the area south of Tate and

Roundish Lakes. Flows are generally massive and less than a few metres thick, although they are locally feldspar-phyric and coarsely hornblende porphyroblastic. Minor laminated lapilli to ash metatuffs also occur.

2) A relatively narrow belt of mixed mafic flows and mafic to intermediate lapilli metatuffs occurs north of Tate and Roundish Lakes, and is transitional northeast of Roundish Lake into felsic and intermediate lapilli metatuffs and minor flows.

3) A 1.5 km wide northeast-trending belt of mafic, intermediate and felsic pyroclastics extends for about 8 km through the Cockwill-Hailstone Lakes area. The belt contains heterolithic metatuff breccias, lapilli-bomb metatuffs, lapilli metatuffs and minor feldspar crystal metatuffs, and varies laterally from boulder size material in the southwest to lapilli size fragments northeast of Cockwill Lake. Several cycles of felsic through intermediate to mafic deposits are present. Crosslaminated feldspar crystal metatuffs are locally present and indicate that at least part of this succession is subaqueous.

4) Between Slaney, Cockwill and Perepelitz Lakes, thick massive feldspar-phyric and nonphyric intermediate to mafic flows predominate. Individual flows are up to 10 m thick. Composite flows in places exceed several tens of metres. Pillowed flows are present locally. Subordinate subaqeous laminated metatuffs and thinly bedded interflow metasedimentary horizons attest to a dominantly subaqueous volcanic environment. Amygdaloidal textures and minor flow breccias also occur locally. The entire sequence is intruded by sheets of massive mesocratic feldspar porphyritic diorite and minor gabbro sills and dykes. Where these minor intrusives form up to 50 percent of the sequence, the distinction between flows and sills is less distinct. Quartz-phyric felsic flows (quartz-eye metarhyolite) are a minor component of this package of rocks.

   A similar sequence of intermediate to mafic subaqueous flows and minor felsic flows intruded by dioritic to gabbroic sills is exposed between Bervin Lake and Highway 102.

5) The area along Larocque Lake and north of Auld and Batter Lakes displays mixed subaqueous pillowed and amygdaloidal mafic and feldspar-phyric intermediate flows overlain by mafic to intermediate meta-agglomerates and massive flows. Felsic metatuffs and quartz-feldspar phyric flows form as much as 20 percent of the volcanic sequence in this area. One horizon with a strike length of at least 14 km and maximum thickness of 300 m extends from Laing Island (Larocque Lake) northeast to Tate Lake.

6) The area between Larocque and Bateman Lakes is underlain by felsic, lesser intermediate, and minor mafic metavolcanic rocks of undetermined depositional character. The metavolcanic units are interbedded with a mixed sequence of metasediments including quartzitic psammites, psammopelites, calcareous psammites, minor calc-silicate rocks and sulphide iron formation. The interpretation of primary relationships between sedimentary and volcanic units has been complicated by intense northeasterly strike-slip shearing and local mylonitization.

Table 1 — Postulated Geologic History of the Roundish-Bervin Lakes Area

Approximate Age	*Geologic Event*
Pleistocene to Recent	Glaciation: glacial deposition, erosion
	Uplift, peneplanation(?), recurrent fault movements(?)
	Faulting: E-W and N-S faulting
	Shearing: NE-SW high strain zones (i.e., McLennan Lake Tectonic Zone and in the Laroque Lake area)
	Minor intrusive event; mafic to felsic dykes
Hudsonian (peak tectonic activity prior ca. 1850 Ma)	Plutonism: syn- to late tectonic, basic to acid plutons and stocks
	Sedimentation: Crew Lake Belt ('greywacke' sedimentation), McLennan Group[1] ('arkosic' sedimentation)
	Major and minor intrusive event: syn- to late-volcanic, basic to acid plutons and stocks, intermediate to acid porphyry dykes and sills
Aphebian (ca. 1877 ± 8 Ma to 1888 ± 12 Ma)	Volcanism and sedimentation: Central Metavolcanic Belt (mafic to felsic composition, predominantly pyroclastic rocks, lesser flows and sediments)
	Minor intrusive event: mafic to intermediate sheeted dyke and sill complex
	Volcanism and sedimentation: Central Metavolcanic Belt (subaqueous mafic to intermediate flows, lesser interflow sediments and tuffs)

[1]Stratigraphic position of McLennan Group not conclusively demonstrated

Metasedimentary Rocks

Metasedimentary rocks occur in very minor amounts within the main volcanic succession. They are generally restricted to thin interflow or less commonly intertuff deposits less than 10 m thick and of limited strike length. **Intervolcanic metasediments** range from very thinly (1 to 3 cm) to thinly bedded (3 to 10 cm) psammitic to psammopelitic rocks. At one location 4 km west of Roundish Lake, planar cross-bedded psammopelitic

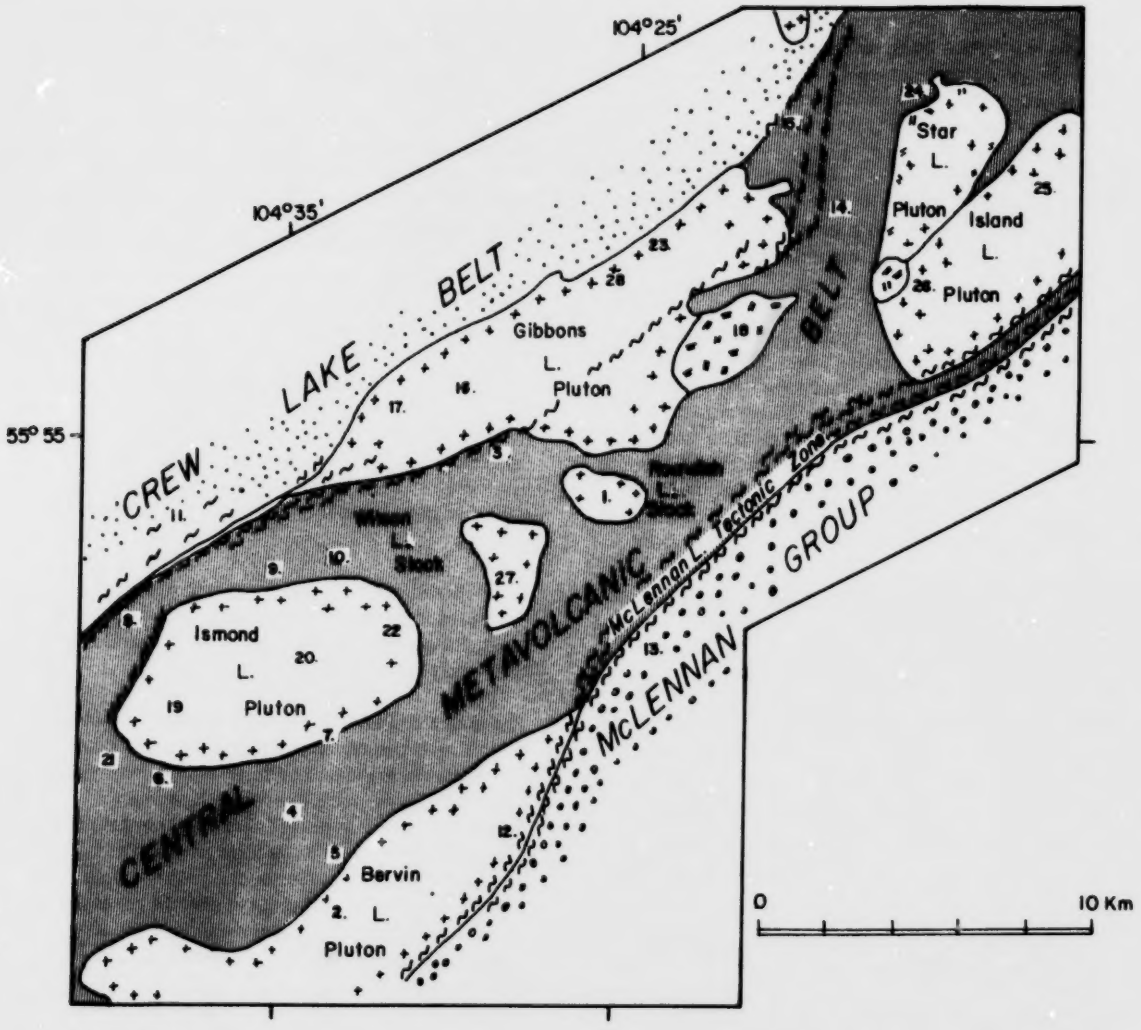

Figure 1 *- General geology of the Star-Roundish-Bervin Lakes area. Intermediate to acid intrusive rocks (crosses), basic to ultramafic intrusive rocks (parallel dashes), 'greywacke' metasedimentary rocks (dots), 'arkosic' metasedimentary rocks (circles), metavolcanic rocks (shaded pattern), shear zones (wavy dashes). Lakes referred to in the text: Roundish Lake (1), Bervin Lake (2), Tate Lake (3), Cockwill Lake (4), Hailstone Lake (5), Slaney Lake (6), Perepelitz Lake (7), Larocque Lake (8), Auld Lake (9), Batter Lake (10), Bateman Lake (11), Thorvaldson Lake (12), McLennan Lake (13), Star Lake (14), Alpat Lake (15), Gibbons Lake (16), Poole Lake (17), Neyrinck Lake (18), Ismond Lake (19), Drummond Lake (20), Carlyle Lake (21), Ell Lake (22), Como Lake (23), Mallard Lake (24), Island Lake (25), Fork Lake (26), Wilson Lake (27), Skalicky Lake (28).*

schists were found within a felsic metatuff horizon, suggesting a subaqeous depositional environment for the tuffs. Metasediments in the area between Larocque and Bateman Lakes comprise an assortment of quartzitic psammites, carbonaceous psammopelitic and pelitic schists, calcareous psammites, minor calc-silicate rock and sulphide iron formation. Preserved sedimentary structures were not observed and the rocks have been subjected to strike-slip shearing, making it difficult to resolve their original depositional environment.

Metasedimentary rocks comprising the **McLennan Group** are dominantly potassium feldspar-rich meta-arenites (meta-arkoses), although subordinate amounts of quartzitic meta-arkose, meta-arkosic wacke and meta-arkosic muscovite schist are also present. Thin (1 to 10 cm) to thick (30 to 100 cm) discontinuous nonparallel bedding is displayed. Crude grain size and compositional variations within individual beds may reflect primary grading and original sand to clay ratios. In general, the rocks were probably moderately sorted sediments with a small proportion of matrix. About 400 m southeast of Thorvaldson Lake, polymictic meta- paraconglomerates occur as narrow lenses (5 to 10 m thick) in sheared

granitoid meta-arkose/psammite. The conglomerate contains elongated granitoid cobbles (64 to 256 mm diameter) in an arkosic wacke (muscovite-quartz-feldspar schist) matrix. A strong tectonic foliation parallel or slightly oblique to compositional banding is developed in metasediments of the McLennan Group towards their junction with metavolcanics of the Central Metavolcanic Belt. Sillimanite-quartz aggregates (faserkiesel) as well as coarse muscovite sheaves (retrogressive after sillimanite) commonly occur along this tectonic foliation.

Metasedimentary rocks of the **Crew Lake Belt** mainly comprise a relatively monotonous succession of psammites, psammopelites and pelites, probably derived from a thick 'greywacke' sequence containing interbedded carbonaceous and sulphidic shales as well as some reworked volcanic material. A very generalized stratigraphic succession (younging from southeast to northwest) is recognized (from oldest to youngest):

1) coarse-grained pelitic gneisses with incipient to widespread *lit-par-lit* quartzofeldspathic neosome;
2) a mixed assemblage of 'rusty' sillimanite-bearing pyritiferous (± pyrrhotite) psammopelitic and pelitic schists, subordinate orange-brown or yellow-brown sulphidic and graphitic sericite-quartz schists, and minor massive quartzites;
3) very well layered 'grey' psammites and minor psammopelites;
4) poorly stratified to massive 'grey' psammites and granitoid 'arkosic' psammites.

The transition between metasediments of the Crew Lake Belt and metavolcanics of the Central Metavolcanic Belt has been obscured by the emplacement of the Gibbons Lake Pluton as well as by later shearing between the two belts. In the Star-Alpat Lakes area to the northeast (Thomas, 1984), the transition between metavolcanic and epiclastic metasedimentary rocks is characterized by a narrow belt of metamorphosed reworked tuffaceous deposits. It is not clear whether a similar transition exists in the present area.

Minor Intrusive Dykes and Sills

Minor intrusive rocks of apparent pre-plutonic age include intermediate, basic and minor ultramafic sills and dykes. The following varieties have been recognized:

1) melanocratic to mesocratic feldspar-porphyritic metadiorite and metamicrodiorite;
2) mesocratic nonporphyritic metadiorite to metagabbro;
3) layered leucocratic to melanocratic metagabbro;
4) uralitized metapyroxenite and hornblendite.

These minor intrusives are interpreted to be synvolcanic, occurring as a concordant to subconcordant sheeted complex. The high-angle crosscutting dykes which also occur are interpreted as both feeder pipes for the overlying volcanic deposits and overlying sills. The sills and dykes are generally uniform in thickness over strike lengths of several hundred metres and are less than a metre to several tens of metres thick. Contacts with wall rocks are usually discrete and straight although local irregular apophyses and bulbous protrusions of dyke into the country rocks also occur. Neither chilled dyke margins or hornfelsed wall rocks have been macroscopically distinguished. Contact strain within wall rocks and dyke margins is generally absent, although zones of shearing less than 20 cm wide were noted in some wall rocks. Dilational offsetting of wall rocks by dyke intrusion is common. One metagabbroic to metapyroxenitic sill-like intrusion 20 to 350 m wide was traced along strike for about 7 km south and southwest of Perepelitz Lake. At its widest intersection, this body displays leucocratic to melanocratic compositional layering ranging from centimetre-scale rhythmic beds to metre-thick layers. Layers display density grading with mafic mineral accumulations at the base, vague crosslaminations and rudimentary channel-like features. The location of this particular sill closely conforms to a narrow northeast-trending magnetic high which extends for 9 km through the area (Aeromagnetic Series Map 4790G). There is an apparent absence of feldspar-porphyritic and nonporphyritic metadiorite, metagabbro and metapyroxenite sills and dykes amongst the pyroclastic accumulations between Cockwill and Bervin Lakes as well as north and northeast of Roundish Lake, possibly suggesting that the pyroclastic deposits are younger than the flow sequences hosting the minor intrusives.

Intermediate (andesitic-dacitic) to acid (rhyolitic) porphyry dykes and sills intrude all metavolcanic units throughout the area. These intrusions appear to be post-plutonic in age, as evidenced by their emplacement cross-cutting the Ismond Lake, Star Lake and Island Lake Plutons (Thomas, 1984). The dykes and sills generally form sheets less than a metre wide although in a few localities, notably north of Bervin and Batter Lakes, they exceed 50 metres in width. Some acid sills may become difficult to distinguish from felsic metavolcanic rocks, although the porphyries are generally coarser grained and contain relatively large euhedral blue quartz and/or potassium feldspar phenocrysts up to 1 cm diameter. Dykes intruding the Ismond Lake Pluton are broadly similar but less mafic than those described from the Star Lake Pluton (Thomas, 1984). Dykes of intermediate composition, which are locally sheared, commonly host relatively coarse hornblende, biotite or chlorite aggregates (3 mm or more in diameter) which are thought to be retrogressive after pyroxene or amphibole phenocrysts.

The minor intrusive rocks described above appear to be restricted entirely to the Central Metavolcanic Belt.

Major Intrusions[1]

Major intrusions occupy approximately 30 percent of the map area. Intrusions exceeding 40 km^2 in size include the

[1]Major intrusions have been variably affected by late regional metamorphism.

Bervin Lake, Ismond Lake and Gibbons Lake Plutons. Smaller stock-like intrusions, less than 5 km² in size, include the Wilson Lake and Roundish Lake Stocks, as well as several small unnamed lens-shaped intrusions.

The **Gibbons Lake Pluton** is flanked by Crew Lake Belt metasediments to the northwest and metavolcanic rocks of the Central Metavolcanic Belt to the southeast. It forms a northeast-trending elongated composite intrusion about 15 km long and 5 km wide. The pluton is dominantly intermediate in composition, although a continuum through to basic rocks exists along its southeast margin. Rock types present include leucocratic hornblende-biotite diorite to monzodiorite, subordinate hornblende-biotite granodiorite to monzonite, coarse-grained megacrystic feldspar tonalite, biotite-hornblende gabbroic diorite, gabbro and anorthositic gabbro. A megacrystic feldspar tonalite forms a distinctive 100 to 500 metre wide semicontinuous outer margin to the intrusion. This member also forms a narrow (50 to 300 m wide) 10 km long sill which extends southwest to Forbes Lake. Leucocratic to melanocratic gabbros and gabbroic diorites occur in the area around Neyrinck Lake. Rhythmic layering, channel-like features and chalcopyrite-pyrrhotite mineralization are features of the gabbroic rocks at Neyrinck Lake (Thomas, 1984). Crosscutting relations were not observed among the various rock types comprising the Gibbons Lake Pluton. The transition between rock types is characterized by subtle to marked mineralogical and textural changes over short distances.

The **Bervin Lake Pluton** forms an elongated northeast-trending intrusion, measuring about 11 km by 4 km, along the southeast margin of the Central Metavolcanic Belt. The intrusion cuts metavolcanic rocks on its northwest flank and appears to intrude arkosic metasediments of the McLennan Group to the southeast. As the southeast margin of the Bervin Lake Pluton is also the site of extensive shearing related to the McLennan Lake Tectonic zone (Thomas 1984; Lewry, 1983), original intrusive relations between the pluton and McLennan Group were not confirmed. The intrusion is dominated by biotite (± hornblende) granite to granodiorite with lesser amounts of syenogranite and biotite-hornblende leucodiorite. Due to limited exposure over much of the intrusion, it is not clear whether the various rock types represent separate intrusive phases or reflect *in situ* differentiation within the body. Extensive epidotization (greater than 50 percent epidote) of metavolcanic rocks which occurs along the northwest flank of the intrusion may be due to contact metamorphism and hydrothermal activity related to the emplacement of the Bervin Lake Pluton.

The **Ismond Lake Pluton** forms an oval-shaped body which intrudes metavolcanic rocks between Larocque and Perepelitz Lakes. The intrusion is remarkably homogeneous compared to the Gibbons and Bervin Lake Plutons. It is primarily composed of biotite granite to quartz monzonite, with very minor granodiorite and leucodiorite generally confined to narrow zones along the margin. Narrow northeast- to north-northeast-trending intermediate (andesitic to dacitic) and quartz-feldspar felsic porphyry dykes intrude the pluton in the Drummond and Ismond Lakes area. Zones of cataclasis, mylonitization and quartz veining also occur in these areas. Along the southwestern and western margins of the pluton, fine to coarsely disseminated chalcopyrite and pyrite occur in both the intrusion and immediately adjacent country rocks.

The **Roundish Lake Stock** outcrops as a narrow area around the shore of Roundish Lake and presumably largely underlies the lake. The intrusion consists of biotite (± hornblende) quartz-rich granite to quartz monzonite with minor amounts of diorite and syenogranite. Along the south margin, mafic to intermediate metavolcanic wallrocks appear to have been mildly hornfelsed. The **Wilson Lake Stock** is poorly exposed, underlying the area west of Wilson Lake. The intrusion is made up of leucocratic quartz-rich granites (greater than 30 percent quartz) and lesser amounts of leucocratic biotite (± hornblende) quartz monzonite and granodiorite. Narrow zones of intrusion breccia are locally developed along the margins of the stocks.

Several small, generally elongated lensoid intrusions of dominantly leucocratic hornblende-biotite diorite and hornblende-biotite granodiorite intrude the metavolcanic sequence. These small unnamed intrusions commonly incorporate abundant metavolcanic xenoliths (possibly roof pendants) and display widespread 'granitic' veining of the wallrocks along gradational or migmatitic contacts. One of the larger of these unnamed intrusions extends for about 4 km northeast of the southeast corner of Roundish Lake. The intrusion is up to about 800 m wide but breaks up into a series of narrow fingers to the northeast. Post-intrusion shearing and quartz veining is also widespread in this body.

A broad grouping of the plutonic rocks is given in Table 2.

Structure

All of the supracrustal rocks in the area have been recrystallized by regional metamorphism and now exhibit variably developed penetrative fabrics. Almost all of the supracrustal rocks possess a schistosity (S_1) which is either conformable or slightly oblique to primary layering of the units. A second generation schistosity (S_2), believed to be axial planar to local folds, is developed slightly oblique to S_1. Foliation in major intrusive rocks is variable, ranging from strong penetrative fabrics, generally best developed along their margins, to entirely massive in habit. Linear fabrics are not as pervasive in this map area as in to the Star Lake area where a prominent LS fabric prevails in most rocks (Thomas, 1984). Good lineation occurs in pyroclastic rocks in the Cockwill Lake area where a steep northwest rodding of clasts occurs in tuff breccias, agglomerates, and lapilli tuffs.

Table 2 — Major Intrusion Types in the Star-Roundish-Bervin Lakes Area

Intrusion Examples	*Dimensions, Plan Shape*	*Composition*	*Intrusion-Country Rock Relationships*	*Postulated Tectonic Setting*
Type 1				
Star Lake Pluton Gibbon Lake Pluton Bervin Lake Pluton	40 km², elongated, amoeboid-shaped	Composite or multiphase; gabbro to granite; well defined to poor compositional zonation; xenolithic screens locall prevalent	Contact strain between intrusion and country rocks generally low; comformable to locally discordant contact; poor definition of intrusive on airphotos	Calc-alkali, moderately to strongly differentiated mesozonal plutons passively emplaced in or near comagmatic volcanic rocks, synvolocanic
Unamed Stocks	5 km², oval, lensoid	Variable; diorite to granite abundant supracrustal xenoliths (roof pendants ?)	Contact strain low; migmatitic injection-veined wallrocks	Small apophyses or cupolas related to Type 1 intrusions
Type 2				
Islans Lake Pluton Ismond Lake Pluton	40 km², round, oval	Homogeneous; leucogranite-quartz monzonite, minor intermediate composition rocks restricted to narrow marginal zones; intrusion breccias common	Contact strain between intrusion and country rocks locally high (shearing, drag folding); semi-conformable wrapping of cover units and prominent 'necking' of surpacrustal rocks at ends of intrusion (strain shadows); arcuate, lobate structural grain; good definition of intrusion on airphotos	Higher level fractionated diapiric plutons
Type 3				
Wilson Lake Stock Roundish Lake Stock	5 km², round, oval	Honogeneous; leucocratic quartz-rich (30 percent quartz) granite, minor quartz monzonite-granodiorite	Contact strain between intrusion and country rocks low; sharp truncation of supracrustal units; mildly to moderately hornfelsed wall rocks	Late syn- to post-orogenic epizonal to mesozonal silicic intrusions

Primary volcanic and sedimentary features are preserved locally, enabling a gross interpretation of the structure and stratigraphy of the area. Primary structures which gave reliable facing information include crosscutting flow relations, crosslaminated bedding and pillow shapes, although the last mentioned are only locally reliable. Other primary structures include graded bedding in pyroclastic deposits, amygdules in mafic and locally intermediate flows, alignment and fining of phenocrysts in feldspar-phyric flows, and gross compositional bedding. The author's preliminary interpretation of the structural and stratigraphic relationships in the area is an overall younging of the metavolcanic sequence from southeast to northwest. A northeast-trending, tight synclinal structure occupies the area between the Ismond Lake and Bervin Lake Plutons. Minor parasitic folds of limited strike length occupy the southeast limb of the syncline. This folding may be the product of either 1) passive draping and infolding of cover rocks between rising (diapiric) plutons, or 2) regional compression of the supracrustal rocks between competent plutonic bodies.

Country rocks adjacent to the Ismond Lake Pluton appear to semiconformably wrap around the intrusion. Prominent 'necking' of units occurs to the southwest and northeast of the pluton and resembles megascopic strain shadows. Both the Wilson Lake and Roundish Lake Stocks sharply truncate the gross stratigraphic layering of the supracrustal cover rocks. There is little evidence of significant contact strain (i.e., shearing, drag folding) existing between the stocks and their host rocks.

Intense cataclastic deformation occurs in a number of northeast- to north-northeast-trending zones in the area. Deformation in these zones reflects heterogeneous strain ranging from moderate (augen structure, well developed schistosity) to high (flasered structure, slaty fracture cleavage, protomylonite) to very high (mylonite, phyllonite). A zone of moderate to very high strain occurs in the area extending northeast along the west shore of Larocque Lake through Tate Lake and northwards to Star Lake. In this zone, shear fabrics generally dip steeply (80° to 85°) to the northwest, although relatively moderate dips (60° to 70°) also occur. Several discontinuous northeast-trending shears cut through rocks between Larocque and Bateman Lakes; these may be splays off the more regionally developed structure described above. North-northeast-trending and northwest dipping (25° to 40°) shear fabrics are developed along the west end of the Ismond Lake Pluton, between Carlyle and Larocque Lakes. Deformation affects the pluton as well as adjacent metavolcanic rocks and is thought to be related to contact strain occurring during intrusion.

The northeast-trending McLennan Lake Tectonic Zone (Thomas, 1984) has been traced through the area between McLennan Lake and Highway 102, southeast through Asbell Bay (McLennan Lake) and between Minuhik and Thorvaldson Lakes. This belt of anastomosing zones of intensely deformed rocks appears to be up to 1.5 km wide in the Star Lake area (Thomas, 1984) but rapidly narrows to less than 300 m in the Asbell Bay area. The zone cuts across metavolcanic rocks, 'arkosic' metasediments (McLennan Group) and granites of the Bervin Lake Pluton. Lewry (1983) has postulated that this zone of deformation corresponds to a high angle thrust or limb slide (McLennan Lake Thrust; Lewry, 1983) resulting in the transport of the older volcanics of the Central Metavolcanic Belt over younger and tightly folded 'arkosic' rocks of the McLennan Group. This speculative proposal needs to be substantiated by further work on the relative ages of the two terrains and analysis of the kinematics within the McLennan Lake Tectonic Zone.

Metamorphism

All rocks in the area have been variably recrystallized and transformed by regional metamorphism. Mafic metavolcanics (i.e., metabasalt, metabasaltic andesite) are amphibole + plagioclase rocks with variable amounts of chlorite, biotite and epidote; mafic content exceeds 35 percent in these rocks. Intermediate metavolcanic rocks (i.e., meta-andesite, rnetadacite) are primarily amphibole + biotite/chlorite + plagioclase rocks with subordinate potassium feldspar, carbonate, quartz and sericite; mafic mineral content is between 15 and 35 percent in these rocks. Felsic metavolcanic rocks (i.e., metarhyolite, metarhyodacite, metadacite) are plagioclase ± potassium feldspar + quartz with minor muscovite, epidote, biotite, chlorite and occasional amphibole; mafic mineral content is less than 15 percent of the rocks. Late hornblende porphyroblasts, some exceeding 1 cm diameter, are prevalent in mafic and intermediate metavolcanic rocks throughout the area. Hornblende porphyroblasts are typically well-formed idioblastic grains which postdate the S_1 fabric. Late cataclastic deformation of mafic and intermediate metavolcanic assemblages has resulted in retrogression of hornblende-rich rocks to chloritic and biotitic schists.

Metasediments in the McLennan Group contain quartz-sillimanite *faserkiesel* and coarse muscovite-quartz sheaves (retrogressive after sillimanite). *In situ* metatexis and syn- to post-tectonic growth of muscovite occur in pelitic and psammopelitic rocks of the Crew Lake Belt.

Major intrusions exhibit effects of regional metamorphism in a variety of ways depending on their original mineralogy and timing of emplacement with respect to peak regional metamorphism. Mafic rocks, notably metagabbros at Neyrinck Lake, exhibit amphibole pseudomorphs after pyroxene, while hornblende-bearing plutonic rocks commonly exhibit biotite + chlorite after amphibole. Breakdown of plagioclase to visible epidote and white mica (saussuritization) within granitoid rocks may be attributed to late-stage deuteric conditions during plutonism as well as alteration of feldspar in response to shearing and faulting.

Metamorphic data from the map area suggest middle to upper amphibolite facies conditions were attained in rocks of the McLennan Group and Crew Lake Belt, while lower to middle amphibolite conditions were reached in the Central Metavolcanic belt. Retrogressive metamorphism to upper greenschist facies mineral assemblages accompanied later shearing and faulting.

Mineral Exploration

Past exploration activity in the area can be broadly divided into surveys for base metals in the Crew Lake Belt and for gold in the Central Metavolcanic Belt. A few Cu-Ni and Cu occurrences are also reported in the Central Metavolanic Belt.

Gold

Recent exploration work has been primarily focussed towards gold. The entire map area is currently covered by mineral dispositions and work performed on these is still confidential. To the immediate northeast of the present map area, several gold properties are in advanced stages of exploration or development. The **Star Lake joint venture** between Starrex Mining Corp. and Saskatchewan Mining Development Corp. is scheduled to commence site construction by late 1985 with production slated for April 1987. The Star Lake mine has presently mineable reserves of 181,367 tons grading 0.477 oz./ton Au. The mine is anticipated to operate for three years (SMDC News Release, July 24, 1985). Evaluation of the Mallard Lake-Jolu property (Decade Mine) by Mahogany Mineral Resources Inc. has been underway since 1984 (Thomas, 1984). Three main zones have been outlined with rough tonnage estimates as follows: 1) Mallard Lake, 35,000 tons grading 0.61 oz./ton Au (diluted 15 percent); b) Rod Main, 105,000 tons grading 0.51 oz./ton Au (diluted 15 percent) and c) Rod South, 35,000 tons grading 1.03 oz./ton Au (diluted 15 percent) (Mahogany Minerals Resources Inc., News Release, January 30, 1985).

Reconnaissance surveys by government agencies from 1926 to the early thirties confirmed the presence of gold mineralization in the southern part of the La Ronge Domain (Coombe, 1984). Follow-up evaluation of the region from 1940 to the present identified some 55 gold occurrences in the area between Lac La Ronge and Waddy Lake (Coombe, 1984). The single known gold occurrence in the present map area, the Como, is situated about 2.7 km southwest of Alpat Lake (15)[1] and 2.5 km northeast of Skalicky Lake (28).

Como Occurrence: The Como property was staked in 1961 following the discovery by E. Partridge of a 90 kg quartz boulder that averaged 1.19 oz./ton Au and 4.50 oz./ton Ag from two grab samples (Assessment File 73P16-NW-0001)[2]. Follow-up work on the claims included geological mapping, several trenches and 130 m of diamond drilling. These investigations identified two gold-bearing quartz veins (Veins 1 and 5). Vein 1 returned 0.28 oz./ton Au and 0.40 oz./ton Ag from a 0.7 m wide chip sampling section. Vein 5, which produced a grab sample assaying 0.32 oz./ton Au, was tested by two drillholes. One hole intersected the vein and gave a value of 0.01 oz./ton Au over 4.1 m (Coombe, 1984). The veins occur in porphyritic tonalite and diorite of the Gibbons Lake Pluton close to the contact with a narrow keel-like belt of 'greywacke' metasedimentary rocks. Both intrusive and metasedimentary units in this area display effects of local northeast-trending shearing along which fracture-filling quartz is emplaced.

Copper

Past investigations in the area have identified scattered copper occurrences in the Central Metavolcanic Belt. Three occurrences that have seen a small amount of work are found at Neyrinck Lake (18), Cockwill Lake (4) and Tate-Roundish Lakes (3,1).

Neyrinck Lake (18), Studer Showing: Copper-nickel mineralization was reported in gabbroic rocks underlying the Neyrinck Lake (18) area in the mid-sixties by V. Studer. The area was staked and subsequently examined by a number of companies until the mid-seventies. The main zone of mineralization is situated between the northwest shore of Neyrinck Lake (18) and Frog Lake, although chalcopyrite, minor pyrrhotite and magnetite are also found throughout gabbroic rocks in the area. Mineralization occurs as disseminated sulphides with local narrow veinlets or blebs up to a centimetre in diameter. The main zone of mineralization dips steeply southwest, and has a reported strike length of 137 m and width of 9 to 31 m. Assays from the main zone were considered to be low (0.2 to 0.3 percent Cu and 0.05 percent Ni) but a 1.5 m section returned 18.5 g/t Ag (Assessment Files 73P16-NW-0012, 0020, 0021). A grab sample obtained by the author in 1984 from a trench over the main zone gave 103 ppb Au, 136 ppb Pd and 18 ppb Pt.

Cockwill Lake (4), Kazan Claims: Small amounts of pyrite and chalcopyrite are reported from a trenched area about 120 m northeast of a small lake immediately to the northwest of Cockwill Lake (4). Mineralization is reported to take the form of stringers and blebs in very siliceous 'silicified' metavolcanics (Pearson and Froese, 1959). No assay values are available.

Tate-Roundish Lakes (3,1), Thomas Claims: Minor disseminations of pyrite-pyrrhotite and chalcopyrite occur in a number of areas in the Tate-Roundish Lakes (3,1) area. Studer Mines Ltd. trenched and sampled gabbroic rocks of the Gibbons Lake Pluton north of Roundish Lake (1) in 1965 and received assays of 0.5 to 1.0 percent Cu, 0.01 to 0.2 percent Ni, 0.34 g/t Au and 7.20 g/t Ag. In 1966 Great Plains Development Company of Canada Ltd. drilled two holes totalling 293.8 m on an east-northeast-

[1]numbers in parentheses refer to the locations marked on Fig. 1.
[2]Saskatchewan Energy and Mines, Regina.

trending conductor underlying Tate Lake (3). The holes, which identified 1 to 5 percent pyrite-pyrrhotite-chalcopyrite in gabbroic rocks, also intersected metarhyolites, metatuffs and a 10 cm thick graphitic horizon.

Iron-Nickel

Exploration work in the region in the fifties identified a prominent northeast-trending belt of pyrrhotite-pyrite mineralization extending from Forbes Lake to Alpat Lake (15). Initial interest in these massive iron sulphide deposits dwindled by the late fifties but was periodically revived throughout the sixties and seventies with no significant new discoveries. This belt of iron sulphide enrichment has been referred to as the 'La Ronge Pyrrhotite Trend' (Assessment File 73P15-SE-0012).

Larocque-Bateman Lakes (8,11), Keep, Ken, Kel Claims: Massive pyrite-pyrrhotite mineralization was discovered and subsequently staked during 1955-56 in the area extending from Beatty Bay (Forbes Lake) to Bateman Lake (11). A north and a south zone were identified and a total of 1319 m and 1233 m respectively were diamond drilled in 1956. Drilling identified disseminated pyrite-pyrrhotite and minor chalcopyrite in the south zone, with a best intersection being 1.09 percent Cu over 1.52 m (Beck, 1959). Drill core from the north zone failed to yield economic mineralization, although trace amounts of gold, zinc, copper and nickel were returned in assays from several sections (Beck, 1959).

The mineralized zones are found within a belt of hornblende and calc-silicate gneisses, psammitic to psammopelitic metasedimentary rocks and lesser metavolcanic rocks. A positive correlation between calcareous metasedimentary rocks and sulphide mineralization is evident throughout the area, while sulphide accumulations in metavolcanic assemblages is commonly associated with carbonate veining (Assessment File 73P15-SE-0012). Harper (1983) recognized five types of iron sulphide mineralization in the Forbes-Bateman (11) Lakes area: brecciated, bedded, remobilized, veined and disseminated. Minor chalcopyrite and sphalerite mineralization was also recorded.

Recommendations For Further Prospecting

In view of the encouraging prospects for gold developing in the Star-Mallard Lakes (14,24) area, the following preliminary observations are made on the potential for geologically similar environments in this map area. Gold mineralization in the Star-Mallard Lakes area is spatially related to the Star Lake Pluton, a differentiated intrusion ranging from minor gabbroic rocks to essentially dioritic, monzonitic and granitic rocks (Thomas, 1964). Gold concentrations are present in sulphide-bearing quartz veins developed in or adjacent to northeast- and east-trending shear zones cutting the pluton or the country rocks immediately adjacent to the intrusion.

The geological criteria favourable for gold concentrations in the Star-Mallard Lakes area appear to include:

1) Proximity of a differentiated or composite pluton ranging in composition from basic to acid.
2) Presence of shear zones ranging from very strongly foliated (augen and flaser fabrics) to protomylonitic and mylonitic.
3) Development of fracture systems or dilative zones in response to shearing.
4) Emplacement of sulphide-bearing quartz as fissure veins.

The incorporation or intrusion of basic to acid material as xenoliths, roof pendants and dykes (e.g., 21 Zone, Kahn 18, Blindman, Rod Main and Rod South occurrences) may also be a criterion, but the genetic relationship to mineralization is not yet demonstrated.

On the basis of the above observations, a number of areas within the map-area have been identified which display features somewhat analogous to those characterizing mineralization at Star-Mallard Lakes:

Ismond-Drummond Lakes: The area south of Ismond (19) and Drummond (20) Lakes, extending from Slaney Lake (6) to Ell Lake (22) contains numerous quartz-filled fractures. These quartz veins are commonly located in or adjacent to northeast- to east-trending shears cutting granitic rocks of the Ismond Lake Pluton and later dyke rocks.

Gibbons Lake Pluton: North-and northeast-trending quartz-filled tension gashes are widespread in this pluton, particularly where marked shearing has affected the diorite and monzonite members. Several areas that may be worthy of closer attention include a) the east end of Gibbons Lake (16), b) the area immediately north of Tate Lake (3) extending as far northeast as Star Lake (14), and c) intrusive rocks lying east of Skalicky Lake (28), particularly those adjacent to the narrow keel-like metasedimentary bands identified in this area.

Bervin Lake (2) Pluton: Although poorly exposed, the Bervin Lake Pluton nevertheless warrants further work on the basis of being broadly similar to the Star Lake Pluton. Quartz veining is present throughout the intrusion, but is particularly prevalent towards the southeast where there is shearing related to the McLennan Lake Tectonic Zone.

In addition, preliminary evaluation of field data indicates several other areas which may be favourable for gold and base metal mineralization.

Roundish Lake (1) and Wilson Lake (27) Stocks: These stocks appear to sharply truncate the country rocks and may have produced some 'hornfelsing' in them. Wall rocks, notably on the southside of the Roundish Lake Stock, are relatively massive, dense and locally possess a 'splintery' fracture. The wall rocks also contain finely

disseminated pyrite in places. This localized brittle fracturing of competent rocks (possibly hornfelsed metavolcanics) is considered an ideal setting for the emplacement of metal-bearing quartz veins and is roughly similar to that found around the Komis deposit in the Waddy Lake area.

Perepelitz Lake (7): Locally sheared sulphide-bearing quartz veins and 'blue quartz' felsic porphyry dykes occur in mafic and intermediate metavolcanic rocks within 500 m of the margin of the Ismond Lake Pluton around Perepelitz Lake.

Hailstone Lake (5): Widespread epidotization of metavolcanic rocks occurs within 500 m of the margin of the Bervin Lake Pluton, the epidote in places comprising in excess of 50 percent of some rocks. Large massive quartz veins and 'blue quartz' felsic porphyry dykes are prevalent in this area as well. The extent of the epidotization may be indicative of widespread fluid movement through the rocks. During such a pervasive alteration event mobilization and concentration of metals might be expected. Similarly epidotized metavolcanic rocks intruded by 'blue quartz' felsic porphyries and massive quartz veins occur in a small area located about 300 m west of the trigometric survey station in the southwest part of the map area.

Larocque-Poole Lakes (8,17): Intense northeast shearing cuts supracrustal and plutonic rocks between Larocque Lake (8) and Tate Lake (3). The shear zone is essentially confined to the southern margin of the Gibbons Lake Pluton, although a few shears extend for short distances into and northeast of the intrusion. These shears branch off the main zone around a small lake about 2 km southwest of Poole Lake (17). The complex structural slicing and possible 'stacking' of rocks in this area is considered a favourable environment for large scale quartz-filled tension fissures.

Carlyle-Larocque Lakes (21,8): Shallow southwest-dipping shears along the southwest margin of the Ismond Lake Pluton extend from the east shore of Larocque Lake (8) to Carlyle Lake (21). Country rocks are variably deformed, commonly chloritized, and contain scattered *en echelon* quartz-filled tension fissures. Relatively coarse to medium-grained disseminated chalcopyrite is prevalent in both sheared and undeformed granitic rocks along this zone. The presence of copper sulphides, quartz-filled fractures, chloritization and shearing makes it a favourable area for further work.

Ell Lake (22): Large-scale structural 'necking' of metavolcanic units occurs around the northeast end of the Ismond Lake Pluton. If this structural feature reflects a relatively low stress area or tectonic strain shadow, then fluids might have migrated into it. If the fluids contain significant metals, then this area would be a favourable site for metal precipitation.

Neyrinck Lake (18): Gabbroic rocks in the Neyrinck Lake area contain disseminated copper-nickel sulphides, and display primary igneous rhythmic layering. Several grab samples of visibly mineralized gabbros taken by the author assayed up to 178 ppb Au, 136 ppb Pd, and 23 ppb Pt. These gabbroic rocks appear to merit further evaluation with respect to gold and platinum-group element concentrations.

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Project 8521

Geochemistry of Metavolcanic and Plutonic Rocks, Star Lake and Waddy Lake Areas

by B.R. Watters[1]

Walters, B.R. (1985): Geochemistry of metavolcanic and plutonic rocks from the Star Lake and Waddy Lake areas; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

A geochemical study of metavolcanic and plutonic rock units in the central La Ronge Belt is being undertaken in conjunction with field investigations currently being conducted by C.T. Harper and D.J. Thomas of the Saskatchewan Geological Survey. The study is ongoing and to date has been concerned primarily with the Waddy Lake and Star Lake areas (Harper, 1984, this volume; Thomas, 1984, this volume). The geochemical work is aimed primarily at 1) providing lithogeochemical data in support of the field mapping program, thereby permitting a more refined and reliable subdivision of units, and 2) the characterization of rock units, not only as an aid to mapping, but also to determine processes of magmatic evolution, tectonic setting of emplacement, and mineralization chacteristics and potential.

New geochemical data resulting from this project supplements data already in hand for metavolcanic rocks of the Waddy Lake area and other parts of the La Ronge Belt, such as the Churchill River area and the Esmay Lake - Dickens Lake areas (Watters, 1981, 1984; Watters & Armstrong, 1985).

Geochemical Analyses and Data Processing

To date, 75 samples from the Waddy Lake area and 51 samples from the Star Lake area have been analyzed for major and trace elements. Rock types analyzed include mainly metalavas and intrusives, with minor metasedimentary/metavolcaniclastic and mineralized varieties. All samples were analyzed for Si, Ti, Al, Fe, Mn, Mg, Ca, K, Na, P, LOI, Rb, Sr, Zr, Y, Nb, Pb, Th, Ni, Cu, Zn, Ba, Co, Cr, V, La, Au, As, Ag, Mo, Cd and Be. Twenty-nine samples of metavolcanic and intrusive rocks from both areas have, in addition, been analyzed for the rare earth elements (REE) and Hf, Ta, Cs, Th, U and Sc.

A database filing system has been developed for the project, using a Hewlett-Packard Series 80 microcomputer system and the geochemical data is stored on 3.5-inch microfloppy discs. The file has been set up to include much other geochemical data, available from the literature, that is regarded relevant to the project (e.g., data from Gilbert et al. (1980) and Fox and Johnston (1980)). A large amount of software has been developed by the author for data manipulation and graphic representation.

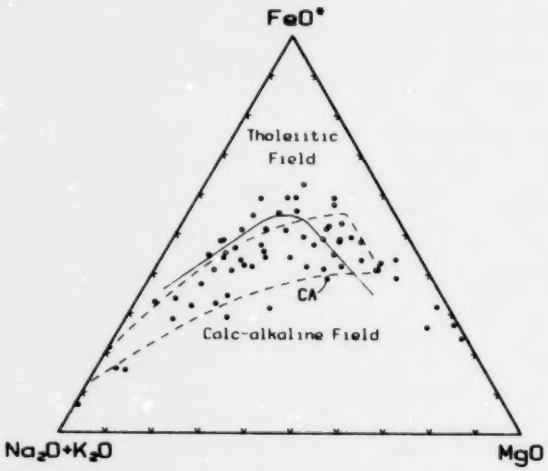

***Figure 1** - AFM plot for metavolcanic rocks from the Waddy Lake and Star Lake areas. Field boundaries are from Irvine and Barager (1971) and the dashed line indicates an area (CA) into which the trends of typical calc-alkaline volcanic suites will plot according to Ringwood (1975). Full circles, Waddy Lake area; open circles, Star Lake area.*

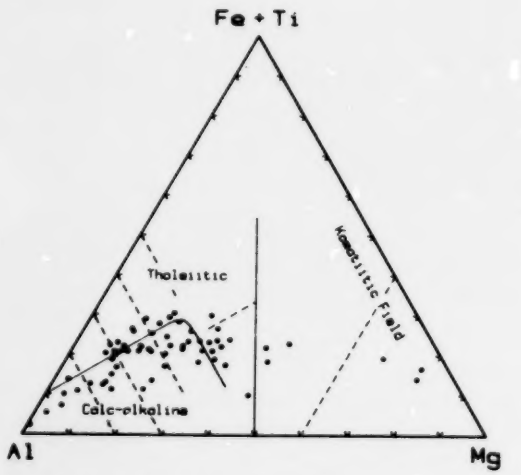

***Figure 2** - Jensen cation plot for metavolcanic rocks from the Waddy Lake and Star Lake areas. Some 'komatiitic' samples may represent intrusives (see text). Field boundaries are from Jensen (1976). Symbols as for Fig. 1.*

Discussion of Results

Much of the work is still in a preliminary stage and detailed studies of certain aspects have been initiated in

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Project contracted to the University of Regina with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

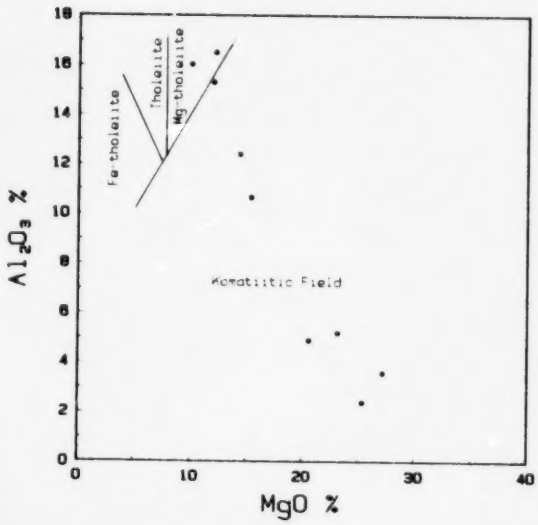

***Figure 3** - Plot of Al_2O_3 vs. FeO (FeOMgO) (after Viljoen et al., 1982) for ultramafic and Mg-basaltic rocks from the South Waddy Lake area.*

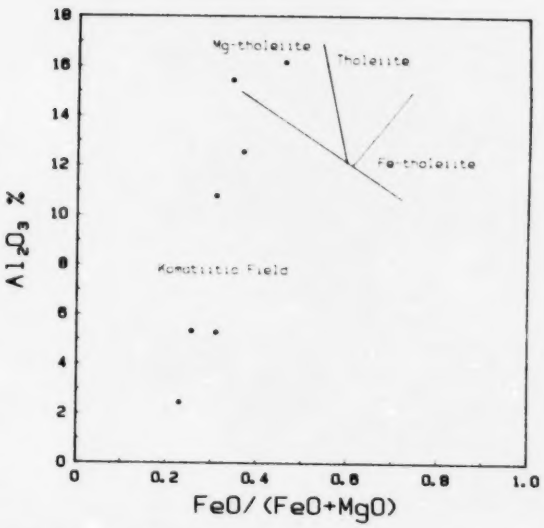

***Figure 4** - Plot of Al_2O_3 vs. MgO (after Viljoen et al., 1982) for ultramafic and Mg-basaltic rocks from the South Waddy Lake area.*

an attempt to throw further light on important specific problems (e.g., the Star Lake Pluton and the ultramafic rocks of the South Waddy Lake area). New data is presented and discussed here, together with data from previous investigations where new data is limited.

Metavolcanic Rocks

The new data for metavolcanic rocks from the Star Lake and Waddy Lake areas are consistent with results of previous studies (Watters, 1981, 1984) and support the idea of a volcanic arc emplacement environment.

Metavolcanic rocks from both areas display similar characteristics on an AFM diagram (Fig. 1), in that the dominant trend is calc-alkaline with some basic to intermediate types displaying a mildly tholeiitic character. The relatively large amount of scatter of data points representing metavolcanics from the Waddy Lake area may be due to the presence of small amounts of pyrite in many of the samples and to alkali element mobility.

A 'Jensen Cation Plot' (Fig. 2), which provides a more reliable classification since it does not include the alkali elements, confirms the dominantly calc-alkaline to mildly tholeiitic character of the metavolcanic rocks. A few samples from the southern end of South Waddy Lake display komatiitic to basaltic-komatiite affinities. However, as indicated by recent fieldwork (Harper, 1985), it is highly unlikely that all of these units are extrusive (e.g., the prominent and extensive ultramafic intrusive mass of Red Hill). Consequently, the term 'komatiitic' is used here in a compositional context without any genetic connotation.

Plots of Al_2O_3 vs. FeO/(FeOMgO) and Al_2O_3 vs MgO (Viljoen et al., 1982) also suggest a komatiitic character for the ultramafic rocks from South Waddy Lake (Fig. 3 and 4). These plots serve to illustrate the high MgO to low Al_2O_3 and low FeO to high MgO characteristics of komatiitic rocks. Although sampling is limited, it appears that a continuum of types may exist between true ultramafic rocks and Mg-rich basalts in this part of the Central Metavolcanic Belt (see also Fig. 2). Because few samples were analyzed in the present study, previous data have been included in these plots (Watters, 1981).

As suggested by Winchester and Floyd (1977), a plot of SiO_2 vs. Zr/TiO_2 (Fig. 5), serves to distinguish between alkaline and subalkaline volcanic rock types. The ratio Zr/

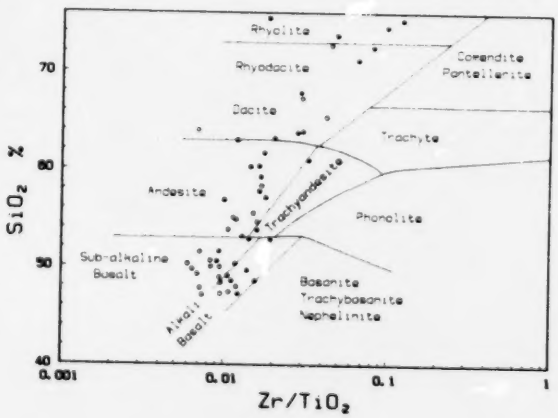

***Figure 5** - Plot of SiO_2 vs. Zr/TiO_2 for metavolcanic rocks of the Waddy Lake and Star Lake areas. Field boundaries after Winchester and Floyd (1977). Symbols as for Fig. 1.*

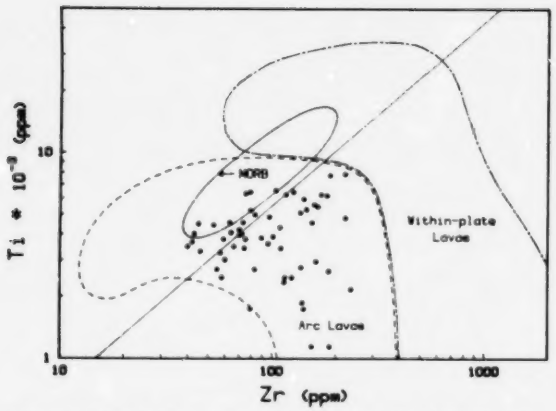

***Figure 6** - Plot of Ti vs. Zr for metavolcanic rocks of the Waddy Lake and Star Lake areas. Field boundaries after Pearce and Norry (1979). Symbols as for Fig. 1.*

TiO_2 constitutes a reliable index of alkalinity since both Zr and Ti are relatively immobile elements, and well-defined subalkaline trends are indicated for the bulk of the La Ronge metavolcanics, with minor alkali basalt.

A volcanic arc character for the metavolcanic rocks from the Star Lake and Waddy Lake areas is strongly suggested by a series of geochemical discrimination diagrams that make use primarily of elements that remain relatively immobile during alteration and metamorphism.

Metavolcanic rocks from the Central Metavolcanic Belt are characterized by low Ti and low to moderate Zr contents, and are confined almost exclusively to the volcanic arc field on Fig. 6. While more scatter is evident on a Cr vs. Y plot (Fig. 7), the metabasalts clearly have

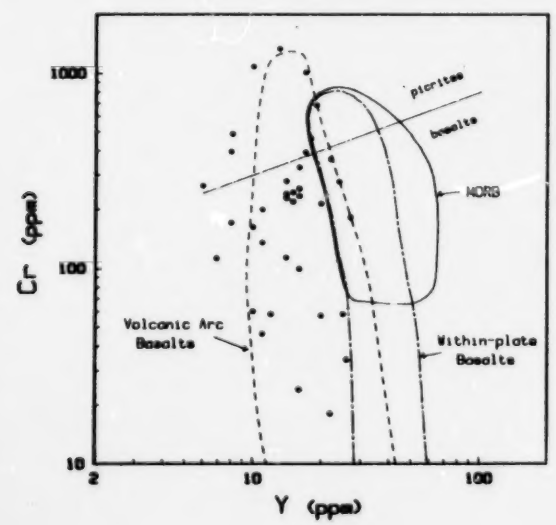

***Figure 7** - Plot of Cr vs. Y for metavolcanic rocks of the Waddy Lake and Star Lake areas. Field boundaries after Pearce (1982). Symbols as for Fig. 1.*

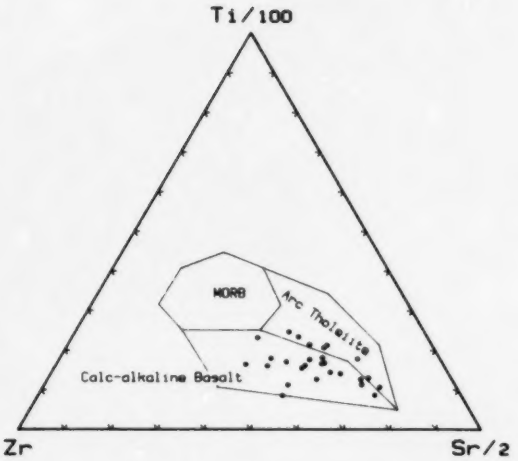

***Figure 8** - Plot of Zr-Ti-Sr for metavolcanic rocks of the Waddy Lake and Star Lake areas. Field boundaries after Pearce and Cann (1973). Symbols as for Fig. 1.*

low Y values typical of volcanic arc types. The Zr-Ti-Sr discrimination plot (Fig. 8), while including an element that may show a degree of mobility during metamorphism (i.e., Sr), also indicates a volcanic arc affinity. The Star Lake basalts analyzed in this study straddle the arc tholeiite - calc-alkaline boundary, while those from Waddy Lake are apparently dominantly calc-alkaline. This apparent difference between the basalts from the two areas is regarded as being due primarily to sampling bias and is therefore not real.

Chondrite-normalized REE distribution patterns for calc-alkaline metavolcanic rocks from the Waddy Lake area (Fig. 9) show low to moderate total REE contents (40 to 87 ppm) and LREE/HREE ratios ((La/Lu)cn 5.4 to 22) with little or no Eu anomaly, all features characteristic of calc-alkaline volcanics from island arcs. Tholeiitic

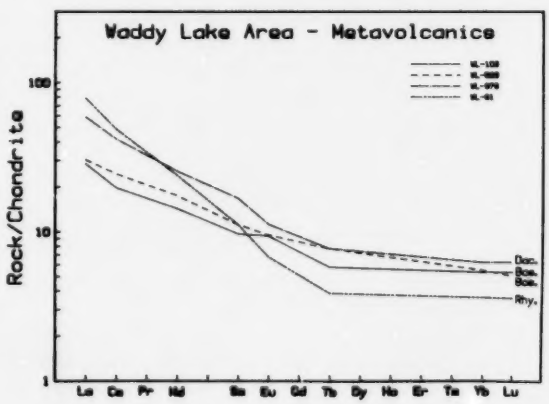

***Figure 9** - Chondrite-normalized REE distribution patterns for calc-alkaline metavolcanic rocks from the Waddy Lake area.*

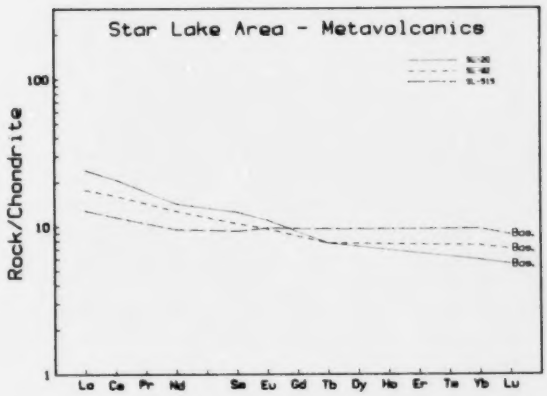

Figure 10 *- Chondrite-normalized REE distribution patterns for tholeiitic metavolcanic rocks form the Star Lake area.*

metabasalts from the Star Lake area (Fig. 10) have low total REE contents (26 to 40 ppm) and low LREE/HREE ratios ((La/Lu)cn 1.5 to 4.3) that can be compared favourably with island arc tholeiites (Cullers and Graf, 1984).

Plutonic Rocks

The Star Lake Pluton is strongly zoned and shows a wide range in composition from leucogabbro-diorite in the outer zone to diorite-monzonite-granodiorite in the middle zone, and granite in the central zone. A transition exists from the outer zone to the core. This chemical zoning corresponds to the mineralogical zoning identified in the field and in thin-section analysis (Thomas, 1984). In the samples analyzed, SiO_2 content ranges from 50 to 56 percent in the outer zone to about 66 percent in the middle zone and about 72 percent in the central zone. Rocks comprising the various zones of this pluton form

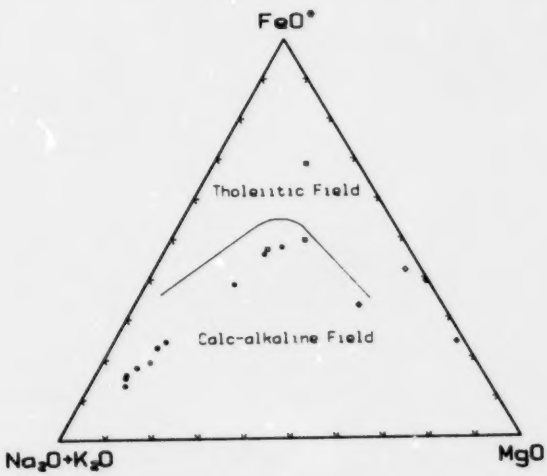

Figure 11 *- AFM plot for intrusive rocks from the Star Lake area. Field boundaries are from Irvine and Barager (1971). Full circles, Star Lake Pluton; open circles, Island Lake Pluton; squares, Neyrinck Lake mafic intrusion; diamonds, Fork Lake intrusion.*

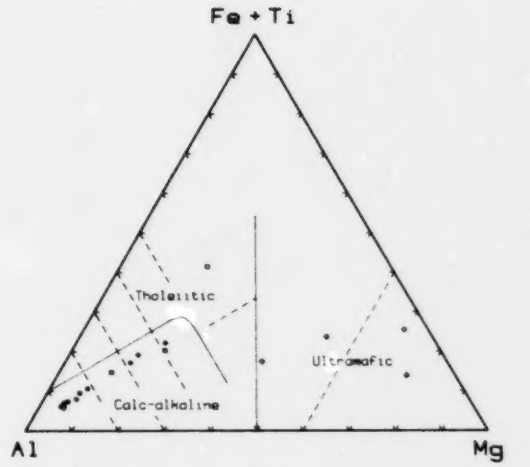

Figure 12 *- Jensen cation plot for intrusive rocks from the Star Lake area. Field boundaries are from Jensen (1976). Symbols as for Fig. 11.*

coherent trends on chemical variation diagrams (e.g., Figs. 11 and 12) and are regarded as genetically related. In broad characterization they are calc-alkaline and very little different in this respect from calc-alkaline volcanics in the vicinity.

Chondrite-normalized REE distribution patterns (Fig. 13) serve to further distinguish between the zones in that, while the profiles for all zones are very similar in shape, there is a marked progressive decrease in total REE contents from moderate (184 ppm) in the outer zone to low (46 ppm) in the central zone. LREE/HREE ratios are low and very similar for all zones ((La/Lu)cn 9.2 to 11.3) and characteristically there is little or no Eu anomaly. The observed decrease in REE contents from mafic to felsic members of the Star Lake Pluton suite is the reverse of normally expected igneous trends, although it is by no means unique (e.g., Pankhurst, 1979; Atherton et al., 1979).

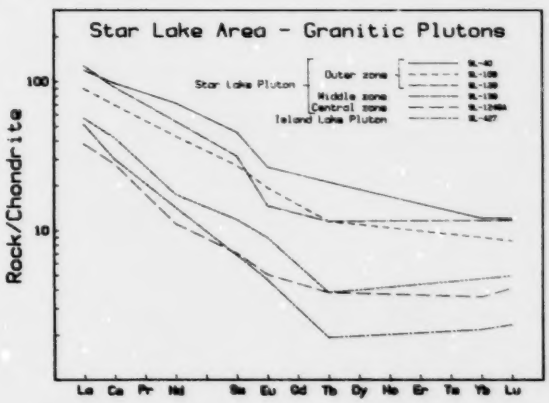

Figure 13 *- Chondrite-normalized REE distribution patterns for the Star Lake and Island Lake Plutons.*

Geochemical, field and petrographic data are consistent with a fractional crystallization model for the origin of the compositional zoning in this pluton. It is suggested, speculatively at this stage, that fractionation of a calc-alkaline gabbroic-dioritic parent magma, represented perhaps by the outer phase of the body, could have taken place primarily in a larger reservoir at depth, producing progressively more felsic magma phases in its upper zones. Following an initial injection of mafic magma upwards into the site of the Star Lake Pluton, magma was intermittently, or perhaps by a slow but continuous 'streaming' process, injected upwards from the reservoir, during this fractionation process, replacing the inner zones of the early mafic magma body with increasingly more siliceous magma. Some *in situ* fractionation may have occurred in the Star Lake body but was probably not important.

The progressive decrease in total REE contents, from the more mafic outer zones to the granitic central zone, indicates that the REE behaved as compatible elements with bulk solid-liquid partition coefficients (D) greater than unity during fractionation. No trace element modelling studies have been conducted as yet, but it is suggested that amphibole and perhaps plagioclase and pyroxene were fractionating phases. It is further possible that accessory phases such as apatite and sphene may have been involved in order to produce the marked REE depletion displayed by the inner zone rocks.

Fractionation of plagioclase would be expected to lead to strong negative Eu anomalies; however, the simultaneous crystallization of amphibole would tend to balance out this tendency. The presence of small negative Eu anomalies in the outer zone rocks (Fig. 13) may indicate that, during the very early stages of evolution of the Star Lake Pluton magmas, plagioclase fractionation was important. Alternatively, the small negative Eu anomalies in these rocks may represent an artifact of the processes that produced the parent magma. The dominance of amphibole as a major fractionating phase in producing the intermediate to felsic magmas is indicated by small positive Eu anomalies and by possible negative Tb anomalies in these rocks (Fig. 13). It can be mentioned, in support of this, that margin zone rocks of the pluton contain abundant plagioclase, relict pyroxene and amphibole, at least some of which appears primary (Thomas, 1985, pers. comm.).

The parent gabbroic-dioritic magma may have been derived by melting of amphibolitic or hydrous mafic granulitic source rocks in the roots of the La Ronge arc complex. Such a source would account for the general calc-alkaline character of the pluton and for the slightly but consistently higher total REE contents in the marginal zone of the pluton compared with those in the metavolcanics (cf. Figs. 9, 10 and 13). This would suggest that the source rocks had low $^{87}Sr/^{86}Sr$ initial ratios similar to the metavolcanics and other plutons in the La Ronge Belt (Watters and Armstrong, 1985). Isotopic studies on a representative suite of samples from the pluton are in progress to verify this.

An alternative model for the evolution of the Star Lake magmas is that of varying degrees of partial melting of amphibolitic or perhaps hydrous mafic granulitic source rocks in the roots of the La Ronge volcanic arc. Partial melting of such source material would produce magmas of calc-alkaline character, while leaving a residue rich in amphibole, plagioclase and perhaps accessory phases such as sphene. Felsic melts would be relatively depleted in REE because of the small degrees of partial melting involved, while the residual amphibole would retain most of the REE fraction. Concentrations of REE in the intermediate and mafic magmas would be correspondingly higher due to the higher degrees of partial melting with more and more amphibole (and plagioclase) entering the melt fraction.

While a model involving varying degrees of partial melting may have been important in a regional sense as a mechanism for producing plutons in the Central Metavolcanic Belt of differing bulk composition, the fractional crystallization model, as described above, is favoured for the Star Lake Pluton. A normal partial melting model would imply that the early magmas were felsic and the later more mafic, with a similar sequence of intrusion. Although there is no good evidence to indicate the sequence of intrusion, it would seem more reasonable for the felsic magmas to have been emplaced into the central parts of an existing mafic body. Possible evidence for this lies in the presence of mafic xenoliths in the granitic inner zones (Thomas, 1985, pers. comm.), which may represent altered blocks of displaced mafic rock as seen in the outer zone. The isotope study should also help to resolve some of the problems concerning evolutionary trends and the nature of the source rocks.

It is considered unlikely that the zoning in the Star Lake Pluton is due to contamination by metavolcanic country rocks of an original granitic magma body (as represented by the core zone). There is a conspicuous lack of xenoliths in the outer zone of the body (Thomas, 1985, pers. comm.) and, as pointed out above, total REE contents in the marginal zone are higher than those in the metavolcanics. In the context of a contamination model, this could only be explained if a very selective assimilation process occurred, involving REE-rich accessory mineral phases, and this is considered unlikely.

Evolutionary models such as those outlined above also provide mechanisms whereby the origin of unzoned plutons in the area, such as the Island Lake Pluton, can be explained. The Island Lake Pluton is homogeneous and compositionally very similar to the central zone of the Star Lake Pluton; the two are indistinguishable on the basis of major element geochemistry (Fig. 11 and 12). However, the REE distribution pattern of a single sample from the Island Lake body shows a slightly higher LREE/HREE ratio ((La/Lu)cn 21.8) than granite from the Star Lake Pluton (Fig. 13). This feature is due to a relative

depletion in the HREE; the levels of concentration of the LREE are the same. Also notable is the V-shape of the Island Lake granite profile, with a possible negative Tb anomaly.

The origin of the Island Lake Pluton can be accounted for either by fractional crystallization or partial melting. Applying a fractionation model, as for the origin of the Star Lake body, it may be suggested that the Island Lake Pluton originated by a single injection of felsic magma representing a slightly later phase of fractionation than the Star Lake granitic magma. The dominance of amphibole as a fractionating phase is indicated by the REE patterns. Alternatively, small degrees of partial melting of amphibolitic source rocks, with amphibole as a principal residual mineral, could be expected to produce granitic magmas having the observed characteristics. It is hoped that further work will permit a distinction to be made between the two processes for this and other plutons in the La Ronge Belt.

The Neyrinck Lake mafic intrusive is compositionally very similar to the outer zone of the Star Lake Pluton (Figs. 11 and 12) and may constitute an early mafic phase of a large 'granitic' pluton (Gibbons Lake Pluton) similar in compositional structure and origin to the Star Lake body. Notably, however, the Neyrinck Lake body displays primary igneous lamination and layering (Thomas, 1984), implying at least some *in situ* fractionation. Such features are not present in the marginal zones of the Star Lake body. A single sample from the Neyrinck Lake body shows strong iron enrichment but this is due to mineralization (Figs. 11 and 12).

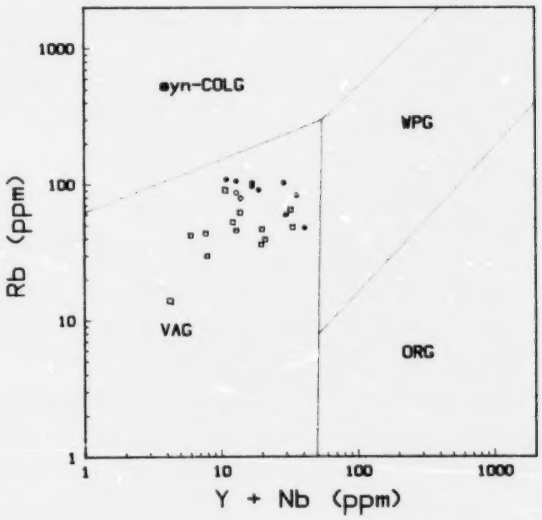

Figure 14 *- Rb vs. (YNb) discriminant plot for 'granitic' rocks (SiO_2 greater than 56 percent) from the Star Lake and Waddy Lake areas. Field boundaries are from Pearce et al. (1984). VAG, volcanic arc granites; ORG, ocean ridge granite; WPG, within plate granites; syn-COLG, syn-collision granites. Full circles, Star Lake Pluton; open circles, Island Lake Pluton; squares, plutons from Waddy Lake area.*

The small Fork Lake intrusion has a marked Mg-rich, ultramafic character (Fig. 12) and cannot be obviously linked compositionally to any other mafic intrusives or extrusives in the area. This intrusion and the Neyrinck Lake body will be studied in more detail in the future in order to attempt resolution of this problem.

Recent work by Pearce et al. (1984) has demonstrated that it is possible to discriminate between 'granitic' rocks from different intrusive settings on the basis of certain trace element relationships. Applying the discrimination criteria laid out by these authors to 'granitic' rocks (SiO_2 greater than 56 percent) from the Waddy Lake and Star Lake areas indicates, without exception, that they are 'volcanic arc granites' (e.g., Fig. 14). Geochemical patterns of 'granite' compositions normalized to ocean ridge granite (ORG) also have distinct characteristics depending on tectonic affinity. Such patterns for the Star Lake Pluton (Fig. 15) show all the features outlined by Pearce et al. (1984) as being typical of volcanic arc granites (i.e., enrichment in K, Rb, Ba, Th, Ce and Sm relative to Ta, Nb, Hf, Zr, Y and Yb). A further characteristic is the low value of Y and Yb relative to the ORG normalizing composition.

Although a great deal more research needs to be done regarding possible pathfinders for mineralization, it appears that granitic rocks in the Star Lake and Waddy Lake areas that have high Au values also have higher than usual concentrations of As, Co, La and Mo. A single sample of mineralized gabbro from the Neyrinck Lake basic intrusive displays an association of relatively high concentrations of Cu, Ni, Zn, Au, Ag, Y, Zr, Ba, Co and La.

Conclusions

New geochemical data for metavolcanic rocks from the Star Lake and Waddy Lake areas support the interpretation of the La Ronge Belt as a Proterozoic island

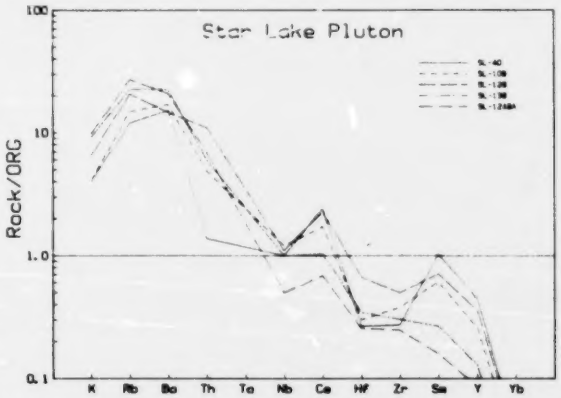

Figure 15 *- Ocean ridge granite normalized geochemical patterns for 'granitic' rocks (SiO_2 greater than 56 percent) from the Star Lake Pluton.*

arc. Some mafic-ultramafic rocks in the South Waddy Lake area display komatiitic and Mg-tholeiitic affinities.

Granitic plutons in both areas have chemical properties typical of volcanic arc granites. Plutons in the Star Lake area, which have been studied in most detail, are calc-alkaline and similar in this respect to the metavolcanics.

Granitic magmas were probably generated by partial melting in the root zones of the La Ronge arc complex and, in a regional context, variations in composition can be explained by varying degrees of partial melting. The wide range of compositions present in the Star Lake Pluton may have originated by successive injections of magma from a larger fractionating magma body at depth.

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Project 8501

Lithogeochemical Investigations in the Forbes Lake Area

by B.R. Watters[1] and R. Macdonald

Watters, B.R. and Macdonald, R. (1985): Lithogeochemical investigations in the Forbes Lake area; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The shoreline vicinity of Forbes Lake was originally mapped by Pearson and Froese (1959) as underlain by metasediments. Field work carried out in the summer of 1984 led Macdonald (1984) to reinterpret most of the shoreline exposures on Forbes Lake as volcanogenic in origin and generally comparable to the metavolcanic rocks on adjacent Laroque Lake.

During the summer of 1985 the area was revisited to review the interpretation and to collect samples for lithogeochemical study, in expectation that the geochemistry would provide additional criteria for distinguishing between metavolcanic and metasedimentary units. Moreover, the area lies on the northwestern boundary of the Central Metavolcanic Belt near the volcanic-sedimentary and structural transition to the predominantly metasedimentary Crew Lake Belt — a situation which in other greenstone belts is favourable for gold mineralization (e.g., Hemlo, Ontario; Lupin Mine, NWT)

Geological observations and sampling were carried out in three areas: a) Forbes Lake, where most of the reinterpreted rocks occur, b) Laroque Lake, where basic to intermediate volcanic rocks of the Central Metavolcanic Belt are prominent, and c) Rennick Lake on the northwestern boundary of the Crew Lake Belt, to ascertain the nature of the metasediments in a more distal position.

Geology

The new geological observations on Forbes Lake reaffirm the existence of predominantly volcanic/volcaniclastic rocks. These are mostly felsic to intermediate in appearance, finely banded or 'ribbed' and largely tuffaceous and fragmental. Some exposures contain relic crystals of quartz or feldspar, which may have derived from phenocrysts. Clots of biotite in many exposures are probably replacive after pre-existing mafic phenocrysts in flows or derive from crystals in tuffs. Clasts up to about 5 cm long are visible in places, most of them felsic in a darker matrix and typically lozenge shaped and narrow.

It has become more apparent this summer that the lithological distinction between Laroque and Forbes Lakes is a function of deformation in combination with original lithology. Along the neck of land between Laroque and Forbes Lake the rocks are variably sheared. This shearing, which can be traced in a zone along the southeastern side of Forbes Lake, coincides approximately with a northwesterly-directed change to more felsic volcaniclastic material. Although smaller shear zones occur on Forbes Lake, most of the felsic volcaniclastic rocks on the lake itself are relatively little deformed. Fragments in the tuffs have apparent (i.e., two dimensional) length:breadth ratios of between about 5:1 and 10:1. In comparison to fragments observed elsewhere in the relatively undeformed parts of the Central Metavolcanic Belt which have similar ratios, the flattening in the Forbes Lake rocks is considered to have a largely original component.

The supracrustal rocks on Rennick Lake appear in the field as little-deformed uniform metapsammites in which the original clastic character is easily discernible. These have been invaded by late granite which has locally produced large spectacular feldspar growths.

Lithogeochemistry

Approximately fifty samples suitable for geochemistry were collected and are presently being analyzed for major elements and a wide range of trace elements (Rb, Sr, Zr, Y, Nb, Cr, Ni, V, Cu, Zn, Pb, Th, Co, Mo, La, Ba and Au).

Preliminary results suggest the following:

a) The bulk of the rocks collected from the Forbes Lake area have major element characteristics of rhyolite. Most have SiO_2 contents in the 70 to 74 percent range and altnough there has apparently been some mobility of the alkali elements, their compositional characteristics do not contradict their reinterpretation as metavolcanics.

b) Some of the Forbes Lake rocks may have been variously reworked by sedimentary processes. Given that most of the rocks still have the major element characteristics of rhyolite, this reworking may not have been extensive . On the other hand, while most trace element contents are consistent with this interpretation, some anomalous ratios (e.g., Zr/Ti) suggest modification by sedimentary processes. Their compositional similarity to rocks of undoubted clastic/volcaniclastic character would support this. Further comment must await completion of the analytical work and interpretation of the geochemical data, especially as regards trace elements.

c) Metavolcanic rocks from the Larocque Lake area are dominantly basaltic with lesser andesite, dacite and

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Project partly contracted to the University of Regina and funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

rhyodacite. The basalts are sub-alkaline types and display compositional characteristics similar to basalts elsewhere in the Central Metavolcanic Belt (Watters, 1981, 1984; 1985, this volume).

d) Despite their distinctive field character, the metasedimentary rocks of the Rennick Lake area have chemical compositional characteristics apparently very similar to the metavolcaniclastic rocks of the Forbes Lake area. We tentatively conclude from this that the Rennick Lake rocks are related, and probably represent a reworked and largely sedimentary distal facies of the Forbes Lake felsic volcanic assemblage.

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Project 8520

Biogeochemical Exploration for Gold in the La Ronge Belt, 1985

by Colin E. Dunn

Dunn, C.E. (1985): Biogeochemical exploration for gold in the La Ronge Belt, 1985; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Studies this year have been directed toward refining the biogeochemical method for gold exploration, and determining local, regional and seasonal distribution patterns of gold and associated elements in common plants. Follow-up work has been conducted in a number of areas (Fig. 1) which yielded anomalous gold concentrations in plants collected during 1984 (Dunn, 1984).

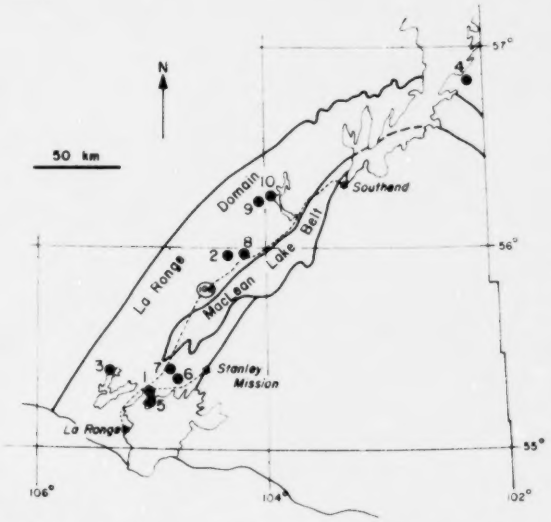

***Figure 1** - Location map. Numbers refer to localities discussed in the text: 1, South Lynx Lake (Table 5) — biogeochemical anomaly, 1984; 2, Star Lake, 21 Zone (Table 6) — gold mineralization; 3, Nemeiben Lake — gold in lake sediments; 4, Karos Lake — gold in lake sediments; 5, Wadin Bay — biogeochemical anomaly, 1984; 6, Freda Lake — biogeochemical anomaly, 1984; 7, Teneycke Lake — biogeochemical anomaly, 1984; 8, Island Lake Pluton — gold in tills; 9, Tower Lake — gold in tills, gold mineralization; 10, Waddy Lake — gold in tills, gold mineralization.*

Sampling Program

Field visits were made in mid-April, late-May to late-June, and mid-August. About 80 percent of the samples were collected in the May/June period. Emphasis was placed upon the collection of alder twigs and outer bark scales of jack pine and spruce. Locally, additional species were sampled for specific tests. Approximately 600 locations were visited from which over 2,000 samples were collected.

Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

In general the sample collection and preparation procedures were the same as outlined in an earlier report (Dunn, 1984), except that this year greater care was taken to obtain just the latest three years of alder twig growth. Where the latest three years of growth was too small to collect easily, note was made of the number of years growth collected. This factor has little bearing on inter-site comparison of gold values, since gold is fairly evenly distributed along the length of an alder twig; however, for other elements the relative age of twigs from one location to the next is critical for meaningful data comparison. For example, molybdenum is highly concentrated in the latest year's growth. Conversely, barium is more concentrated in older growth.

The analytical program this year has again centred upon neutron activation analysis of ashed vegetation, but data have been obtained for a considerably larger suite of elements. Table 1 lists these elements with their detection limits, and shows the usual concentrations of elements present in the three media most commonly sampled.

Of these elements, Ag, Hf, Ni, Se, Ta, W and some rare-earth elements were commonly found to be below detection limits. A standard ash and a duplicate sample were included among each batch of 20 samples submitted. Data obtained attest to the high level of precision and accuracy of this analytical method.

Seasonal Variations

Data presented earlier (Dunn, 1984) indicated a substantial decrease in the gold content of alder leaves and twigs from June to August.

These same shrubs have been sampled on two subsequent occasions, providing information on the startling contrasts in gold accumulation throughout the year (Table 2). The mean gold content of alder twigs from June to August was substantially reduced (by almost 65 percent), only to recover in September and become appreciably enriched by the following April, about three weeks prior to opening of leaf buds. By June of 1985 gold levels had diminished once more to levels lower than the previous June.

The leaves of the alder follow the same pattern of relative gold concentrations in the twigs (Table 3). Highest concentrations occur in early summer, decreasing to a minimum in mid-summer and increasing prior to leaf-fall. Data for September are from leaves that had turned yellow and were, in some places, literally caught as they floated to the ground.

Table 1 — Typical Element Concentrations in Ashed Vegetation, as Determined by Neutron Activation Analysis

Element	Detection Limits	Common Concentrations in Ash		
		Alder Twig[1]	Outer Bark Scales	
			Spruce	Jack Pine
Ag	5 ppm		<5	
As[2]	0.5 ppm	<.5 - 1	2 - 4	4 - 8
Au	5 ppb	10 - 20	5 - 15	10 - 20
Ba	150 ppm	1000 - 3000	3000 - 5000	500 - 1000
Br[2]	0.5 ppm	20 - 40	30 - 60	10 - 50
Ca	0.5%	15 - 25	25 - 35	15 - 30
Co	1 ppm	5 - 20	5 - 10	5 - 10
Cr	2 ppm	<2 - 5	10 - 20	10 - 30
Cs[2]	0.5 ppm	1 - 3	1 - 3	2 - 4
Fe	0.02%	0.1 - 0.2	0.2 - 1.5	0.5 - 2
Hf	1 ppm	<1	<1	1 - 2
Mo	1 ppm	1 - 5	<2	<2
Na[3]	100 ppm		Highly variable	
Ni	200 ppm		<200	
Rb[2]	20 ppm	100 - 500	50 - 100	50 - 150
Sb	0.2 ppm	<2	.5 - 1.5	1 - 4
Sc	0.1 ppm	0.1 - 0.3	1 - 3	2 - 4
Se[4]	3 ppm		<3	
Sr	500 ppm	500 - 2000	500 - 1500	<500 - 1000
Ta	1 ppm		<1	
Th	0.5 ppm	<5	1 - 2	1 - 3
U	0.5 ppm	<5	0.5 - 1	0.5 - 2
W	1 ppm		<1	
Zn	20 ppm	500 - 1500	1000 - 2000	1000 - 2000
La	0.5 ppm	1 - 3	4 - 8	4 - 12
Ce	3 ppm	<3	6 - 12	10 - 20
Nd	5 ppm	<5	<5	5 - 10
Sm	0.1 ppm	0.1	0.5 - 1.5	1 - 2
Eu	0.5 ppm	<0.5	<0.5	0.5 - 1
Yb	0.2 ppm	<0.2	0.2 - 0.6	0.3 - 1
Lu	0.05 ppm	<0.05	0.05 - 0.1	0.05 - 0.15
Ash	%	1.5 - 2.5	2 - 3	1 - 2

Data are based upon a visual appraisal of about 50,000 determinations made on over 1,500 samples. Detection limits obtained at Nuclear Activation Services Ltd., and usual 'background' concentrations in media most commonly sampled for this study. Samples collected from granitic to dioritic substrates; intermediate to basic metavolcanics; and metasediments of arkosic to pelitic origin.

[1]Values in June (concentrations of most elements in alder twigs decrease through the growing season).
[2]Some loss during ashing. Values quoted are consistent in ashed material.
[3]Care must be taken not to contaminate samples or vials with perspiration from bare hands in order to obtain realistic Na values. Values recorded from most bark samples are several thousand ppm Na, whereas alder twigs have a few hundred ppm Na.
[4]On rare occasions some Se is retained in the ash (maximum of 8 ppm Se recorded).

Table 2 — Seasonal variation in the Gold Content of Alder Twig Ash. Ash Yield from Dry Twigs Generally about 2 Percent.

	Gold Concentration (ppb)				
	1984			1985	
Site	Early June	Early August	Mid September	Mid April	Mid June
1a	32	7	23	250	12
1b	53	6	17	47	<5
1c	58	9	20	130	7
2	34	6	15	166	13
3a	29	8	10	37	20
3b	35	7	11	34	7
4a	23	6	13	57	13
4b	25	8	13	41	15
5	25	11	20	27	--
6	8	20	14	20	--
7	29	20	23	75	--
8	35	10	22	58	--
9	23	8	14	51	--
10	12	17	18	33	--
11	24	10	11	53	--
12	25	11	12	42	--
13	14	11	9	66	--
14	21	10	38	48	--
Mean[1]	28	10	17	69	
	(0.56)	(0.2)	(0.34)	(1.38)	

[1]values in parentheses have been recalculated to a dry weight basis

Table 3 — Seasonal Changes in the Gold Content of Ashed Alder Leaves. Ash Yield from Dry Leaves Generally 5 to 6 Percent.

	Gold Concentration (ppb) in 1984		
Site	June	August	September
1c	43	6	19
2	48	7	15
3a	27	18	11
3b	21	6	12
4a	25	7	13
4b	21	13	13
5a	21	11	16
5b	--	7	24
6	6	<5	11
7	11	8	22
8	8	7	8
9	6	6	9
10	10	8	8
11	14	7	18
12	5	10	13
13	13	<5	13
14	8	7	14
Mean[1]	18	8	14
	(0.9)	(0.4)	(0.7)

[1]values in parentheses have been recalculated to a dry weight basis.

Tables 2 and 3 reveal some important points:

1) Background gold concentrations vary substantially throughout the year. Data obtained from several hundred sites indicate that background levels in ashed alder twigs are 20 ppb Au in early summer, 10 ppb Au in mid-summer and 15 ppb Au in late summer. Background in April may be 30 to 50 ppb Au.

2) Greatest anomaly enhancement occurs in the spring, prior to leaf unfurling, at a time when the sap is rising.

3) Anomalous gold concentrations may be ephemeral. For example, the anomalous levels that occurred at site 1 in June 1984 were not apparent later in the year, yet were strongly anomalous in April 1985. Site 1 is located a few tens of metres south of the junction between Hwy. 102 and the Stanley Mission road, in an area where no mineralization is known (no trenching, stripping or drilling has taken place). It is possible that the biogeochemical anomaly is derived from groundwaters containing gold dissolved from a distant source (perhaps hundreds of metres away). Ephemeral anomalies of this sort may possibly be a reflection of remote mineralization, whereas constant anomalies (which would still exhibit seasonal variation) may indicate a local source.

4) The failure of the alders to yield gold values similar to the previous year is probably due to annual vagaries of the climate: since gold concentrations were appreciably higher in April than two months later, clearly there must have been a short period in the spring when the diminishing concentrations were similar to those encountered in June 1984. A complicating factor may be that the successive pruning of the shrubs to the point of almost total removal of recent (3 year) twig growth may have stressed the plant sufficiently to inhibit gold uptake. Limited support for this hypothesis comes from a clump of shrubs sampled five times over the past two years (Table 4): gold concentrations show a steady decrease over the period.

Table 4 — Long-term Change in Gold Content of Alder Twigs (1 Test Site)

	Au (ppb)
May 1983	25
August 1983	22
June 1984	17
August 1984	13
June 1985	9

To Ash or Not to Ash?

On an ash weight basis, gold concentrations are higher in twigs than leaves; yet on a dry weight basis leaves contain almost twice the gold content of the twigs. The present survey has concentrated more on metals in ashed twigs than leaves because:

1) Twigs are available for collection year-round.

2) It was anticipated that the chemical stability of the twigs might be greater than the leaves (although data now show low chemical stability in both media).

3) The higher loss on ignition of twigs than leaves results in ashed twigs yielding a greater concentration of contained gold, and hence greater anomaly contrasts; most samples yield concentrations appreciably above the detection limit of 5 ppb Au in ash, thereby eliminating the problem of evaluating subtle variations near instrumental detection limits.

However, valuable and meaningful data can be obtained from dry alder leaves (cf. Cohen et al., 1985). Reproducible sub-ppb Au analysis of dry leaf samples using neutron activation makes this an attractive alternative to the more time-consuming ashing procedure. Ashing does preconcentrate the samples so that many additional elements may be concurrently determined, and a relatively large sample (50 to 100 g) can be analyzed in ash form compared to the 8 g of dry material required for direct irradiation. By ashing a larger sample, chemical inhomogeneities are integrated. If ashed material is used, however, it must be realized that some elements will partially volatilize from some sample media during ashing (notably Se, Br, Cs, As, Rb and Fe). The final decision depends on the requirements of a particular study.

Table 5 — Gold Concentration in Ashed Components of Vegetation Growing on Sandy Glacial Material Over Metavolcanic Rocks Containing Pyrite and Pyrrhotite.

Sample Type			*Gold (ppb) in ash*			
			Trunkwood	*Bark*	*Twigs*	*Leaves*
Poplar (Populus tremuloides):						
Elevation	8m	(Top of tree)	170	37	31	27
	7m		61	38		
	6m		41	20	18	26
	5m		33	12		
	4m		31	11		
	3m		17	7		
	2m		140	15		
	1m		36	15		
Birch *(Betula papyrifera):*						
Elevation	4m	(Top of tree)	58	82		
	3m		30	44	26	26
	2m		39	63		
	1m		60	70		
Black Spruce *(Picea mariana):*						
Elevation	4m	(Top of tree)	29	48		
	3m		46	73	50	32
	2m		54	49		
	1m		45	43		
Labrador Tea *(Ledum groenlandicum):*					43	23
Blueberry *(Vaccinium spp):* entire aerial portion					— 9 —	
Rose *(Rosa acicularis):* entire aerial portion					— 10 —	
Stiff Club Moss *(Lycopodium annotinum):* entire aerial portion					— 8 —	
Knight's Plume *(Ptilium crista-castrensis):* entire aerial portion					— <5 —	

	Till (7kg sample) — Au (ppb)			
Substrate	*Humus*	*Whole*	*Lt. fraction*	*Heavy Minerals*
Site A	10	9	<5	110[1]
Site B	<5	21	<5	260[1]
Site C	8	<5	8	190

[1]Each contained one grain (50 x 50μ) of abraded visible gold.

No known gold mineralization, but anomalous gold levels in much of the vegetation. Location is close to Hwy 102 and the Stanley Mission Road (UTM 500200E, 6132700N). — Site 1, Fig. 1

Inter-Species Uptake of Gold

Exhaustive sampling of a wide range of media was undertaken at two sites, (Nos. 1 and 2, Fig. 1) of contrasting physical environment:

A. Site 1 (Table 2) - mid-June 1985 (UTM 500200E, 6132700N; NTS 73P-7)

Ridge covered with sandy glacial drift. The nearest outcrop, 50 m to the southwest (approximately on strike), is a greenish banded metavolcanic rock containing traces of pyrrhotite and pyrite.

This site was selected because on several occasions it had yielded high gold concentrations in alder. The closest known mineralization is the Gem showing, 2 km to the southeast. Samples were collected within a radius of 20 m from three alders that in April yielded 47 to 250 ppb Au in twigs. Data presented in Table 5 show that anomalous concentrations of gold are present in the majority of the sample media, although the shallow substrate contains little gold. Noteworthy features of the data are:

1) Above 2 m, poplar exhibits an upward trend of gold concentration in trunkwood, bark and twigs. Leaf concentrations show little variation. Ashed trunkwood contains more gold than the bark.

2) Birch bark is richer in gold than the trunkwood. Twigs and leaves of birch and poplar yield similar amounts of gold.

3) Black spruce trunkwood, bark and twigs have similar gold concentrations, whereas the needles are depleted.

4) Labrador tea is the only low shrub to show a tendency to collect gold.

Either the trees are successfully leaching the gold out of the heavy mineral fraction, or the trees are extracting traces of gold dissolved in groundwaters. The latter explanation is considered the more likely.

B. Site 2 (Fig. 1), Star Lake (21 Zone) - mid-August, 1985 (UTM 544200E, 6205200N; NTS 73P-16)

Clump of vegetation in peat bog, 50 m south of the subcrop of gold associated with pyrite and pyrrhotite in quartz vein occupying a shear zone in quartz monzonite pluton.

Samples were collected late in the summer at a time when gold concentrations are lowest (cf. Tables 2 and 3). Table 6 shows moderate to weakly anomalous levels of gold in most sample media. Of note are the unexpectedly low concentrations in black spruce twigs, and the high enrichment of gold in twigs of labrador tea and leather leaf. Elsewhere it has been found that labrador tea yields erratic results, limiting its effectiveness as a sample medium for gold. In general, the chemistry of the rarer leather leaf shrub parallels that of labrador tea (Dunn, 1981). Data from the willow are higher than expected, in that samples from other localities have yielded low values. This could be a function of species difference, since it is uncertain if the sample collected was pussy willow (*Salix discolor*) or bebb willow (*Salix bebbiana*). The alder data represent at least a four-fold concentration over background values for August. There are few comparative data for this species (*Alnus rugosa*) from mineralized areas, since the more common species is *Alnus crispa*.

Table 6 — Gold Concentrations in Ashed Components of Vegetation Growing in Peat Bog 50 m South of the Subcrop of the Gold-bearing 21 Zone, Star Lake (Site 2, Fig. 1).

Species	*Plant Organ*	*Gold (ppb)*
River alder *(Alnus rugosa)*	Twig	42
River alder *(Alnus rugosa)*	Leaf	23
Birch (probably water birch — *Betula occidentalis)*	Twig	25
Birch (probably water birch — *Betula occidentalis)*	Leaf	22
Dwarf birch *(Betula glandulosa)*	Twig	18
Dwarf birch *(Betula glandulosa)*	Leaf	22
Willow *(Salix spp.)*	Twig	25
Willow *(Salix spp.)*	Leaf	42
Tamarack *(Larix laricina)*	Twig	17
Tamarack *(Larix laricina)*	Needle	38
Black spruce *(Picea mariana)*	Twig	7
Black spruce *(Picea mariana)*	Needle	8
Black spruce *(Picea mariana)*	Bark	16
Labrador tea *(Ledum groenlandicum)*	Twig	110
Labrador tea *(Ledum groenlandicum)*	Leaf	36
Leather leaf *(Chamaedaphne calyculata)*	Twig	140
Leather leaf *(Chamaedaphne calyculata)*	Leaf	42

Biogeochemical Data From Two Areas with Anomalous Gold Concentrations in Lake Sediments

In May 1985, the Geological Survey of Canada released new gold data from 3,512 centre-lake bottom sediments collected from about 50,000 km² of east-central Saskatchewan (Geological Survey of Canada, 1985). A clear positive correlation with many known gold occurrences is apparent, but in addition several single point anomalies occur in areas with no previous record of gold mineralization. Brief visits were made to two lakes which yielded single values of over 300 ppb Au to conduct reconnaissance biogeochemical appraisals of the areas.

A. Lake draining into the northwestern part of Nemeiben Lake (NTS Sheet 73-P6; UTM 476000E, 6142800N). GSC sample site 742588 yielded 316 ppb Au (Site 3, Fig. 1)

A visit was made to this 2 km long lake in mid-June 1985, during which centre-lake sediments were collected from three sites spaced 500 m apart. Traverses were run around the lake collecting alder twigs and spruce bark at 200 m intervals, and two traverses 600 m long were made east-west across the north end of the lake, sampling at 100 m intervals. Thirty-four locations in all were sampled.

Rocks in this area comprise banded pink felsic biotite gneiss with some pegmatitic segregations (particularly to the northwest), and local bands of quartz-rich pelitic schist containing biotite and hornblende. Foliation is generally 010° with a westerly dip of 40°. No mineralization was observed.

The three lake sediments failed to reproduce the high gold value. Concentrations, from south to north, are 0.8, 1.5 and 1.3 ppb Au respectively (dry weight basis). Analysis was by graphite furnace atomic absorption spectrophotometry, following digestion with aqua regia and extraction of gold with MIBK. As confirmation, one sample was also analyzed by INAA (instrumental neutron activation analysis), using direct irradiation of sediment that had been ignited at 475° to eliminate the organic material. The analysis showed gold to be below the detection limit of 5 ppb.

The alders show no enrichment of gold. Background values for alder twigs in June are about 20 ppb Au, and only one sample (24 ppb Au) contained over 17 ppb Au. However, other elements provided more positive indications, particularly around the north and east sides of the lake.

Arsenic levels in ashed spruce bark are commonly below 4 ppm. Over gold/arsenic mineralization at Sulphide Lake, 16 ppm As is present (Dunn, 1984). To the south and west of the lake under study, concentrations are mostly less than 5 ppm As, yet range up to 31 ppm to the north and east (median value of 8 ppm). Spruce bark is slightly (but not significantly) enriched in gold in this area (maximum of 26 ppb compared to background of 10 ppb).

Molybdenum, too, is enriched in alder twigs from the north and east. Whereas the background is less than 5 ppm Mo, up to 76 ppm is present immediately north of the lake.

Zinc is slightly enriched with the Mo and As, and bromine shows a positive correlation. Elevated bromine values have been noted by the author in vegetation in some areas where there is gold enrichment.

B. Karos Lake (NTS Sheet 64D-16; UTM 672800E, 6302000N). GSC sample site 741347 yielded 386 ppb Au (Site 4, Fig. 1)

A few hours were spent at this site in mid-June 1985, collecting five lake sediments and examining the geology of the northeastern part of the lake. Bad weather limited the biogeochemical sampling to eleven samples from five sites extending 600 m parallel to the shore, immediately east of the GSC amomalous gold site.

The predominant lithology is coarse-grained pegmatitic granite with crystals of large feldspar (locally over 5 cm), quartz and books of both muscovite and biotite. Bands of fine-grained biotite gneiss occur within the complex, striking 024° and dipping westward at 50°.

The five lake sediments yielded from 0.4 to 0.7 ppb Au. Multi-element INAA of these sediments did not indicate unusual levels of any of the elements listed in Table 1. Uranium (11 ppm) and Thorium (17 ppm) are slightly elevated.

Vegetation samples included alder, jack pine (bark and twigs) and one sample of labrador tea. The area studied is dominated by jack pine. Gold concentrations are higher than usual for bark (38 and 48 ppb Au) and twigs (23 to 50 ppb Au; mean 33 ppb Au) of jack pine. However, these values are not of great significance. Of interest is one sample of jack pine bark that contains 22 ppb Sb in association with 11 ppb As. Cesium is anomalously high in the alder twigs (9 to 28 ppm, compared to usual levels of 1 to 3 ppm Cs), and is probably derived mainly from the abundant micas.

Comments

Anomalous gold concentrations in lake sediments reported in GSC Open File 1129 were not reproduced in any of the eight sediments collected from the two lakes.

It should be noted that in the current study an Eckman dredge was used for sample collection, whereas the GSC samples were obtained by the torpedo-type sampler (Hornbrook, 1977). The latter obtains greater sediment penetration and obtains samples, therefore, from lower strata. Glacial material may contain scattered flecks of

transported gold, and it is surmised that the 'torpedo' sampler may have reached such a sample. One fleck of gold would be sufficient to generate anomalies of the magnitude recorded by the GSC.

Thus, although the data were not reproducible, it should not be construed that gold is absent. At the Nemeiben Lake occurrence, biogeochemical data indicate anomalous levels of a suite of elements - Mo, As and minor Zn - that are commonly associated with gold mineralization.

The Karos Lake data are from only a 600 m section of the 10 km perimeter of the lake, yet the few samples collected contain gold concentrations in the vegetation that are slightly elevated, along with a local enrichment of Sb and As.

Local Studies

Data received from vegetation samples collected during the 1984 field season pointed to several areas with anomalous gold concentrations that warranted closer investigation. In addition to follow-up work in these areas, studies have been made around several zones of known gold mineralization.

Near Wadin Bay (Lac La Ronge), 4 km northeast of the old Anglo-Rouyn copper mine (UTM 502500E, 6129500N; NTS 73P-7) (Site 5, Fig. 1)

Bedrock - Biotite gneiss striking 080°. Granitic segregations.

Glacial Cover - Nil, to sandy till pockets of uncertain thickness between ridges.

Topography - Ridges following bedrock strike. Locally steep.

Vegetation - Extremely dense forest dominated by black spruce, jack pine and alder between ridges, thinning to open woodland of jack pine upon ridges.

1984 Survey (mid-June) - Gold concentrations found in vegetation from 12 locations were: jack pine bark, 26 to 40 ppb; alder twigs, 10 to 66 ppb; black spruce bark, 7 to 71 ppb.

1985 Survey (early June) - Seven lines were established, spaced 200 m apart normal to the bedrock strike, along which samples were collected at 100 m intervals from 46 locations. Best coverage of the area was obtained from jack pine bark, which proved to contain highly anomalous

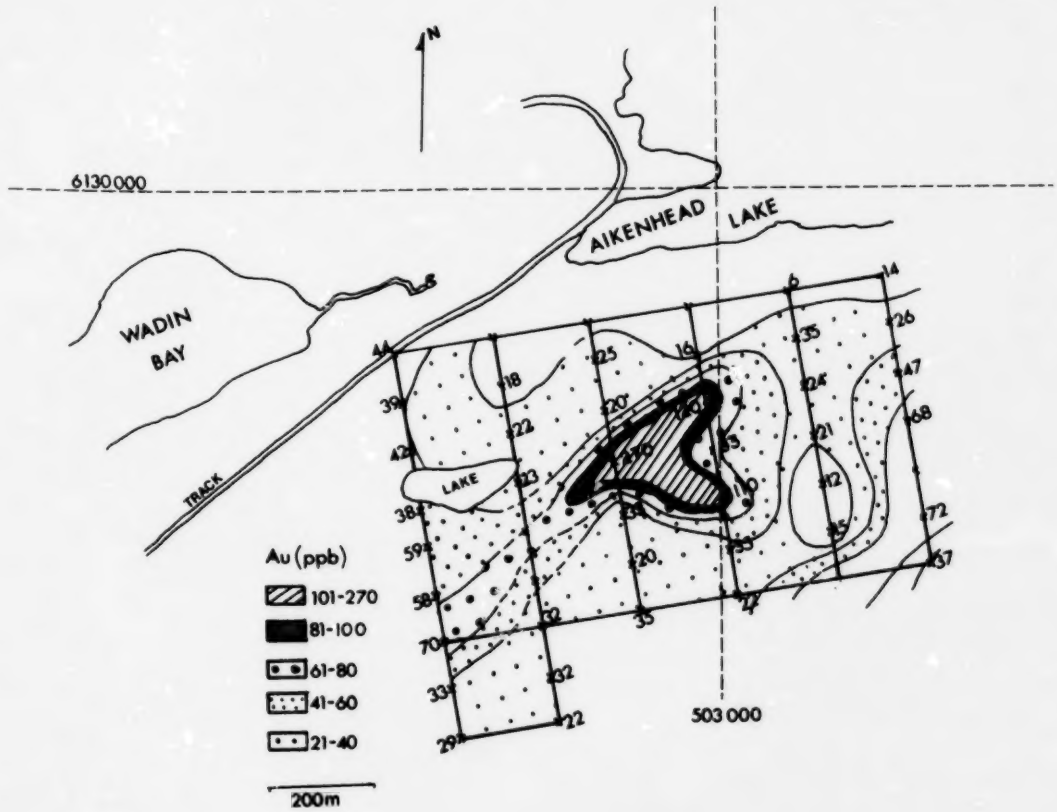

***Figure 2** - Gold in ashed jack pine bark, Wadin Bay area Lac La Ronge.*

levels of gold in the middle of the survey grid (Fig. 2). Arsenic concentrations (up to 16 ppm), and antimony (to 40 ppm, Fig. 3) show a strong sympathetic relationship to gold. Barium and the rare-earths tend to show haloes of enrichment around the Au-As-Sb anomaly. Cesium (up to 20 ppm) and selenium (up to 8 ppm) are enriched in the ashed bark throughout the area, even though a substantial part of these elements is believed to have been volatilized during ashing. Data from the spruce bark confirm the gold enrichment (up to 70 ppb), whereas alder twigs show weak anomalies (25 ppb Au) coincident with, and slightly to the north of, the bark anomalies. Of note are some unusually high (up to 48 ppm) cesium assays from the alder twigs.

Comment - No mineralization has been recorded from this locality, and examination of the bedrock failed to identify a plausible source for the abundance of biogeochemical data which give encouragement for the presence of mineralization. The data are possibly reflecting near-surface mineralization.

***Figure 3** - Antimony in ashed jack pine bark, Wadin Bay area Lac La Ronge.*

East of Freda Lake (UTM 514000E, 6138200N; NTS 73P-7) (Site 6, Fig. 1)

Bedrock - Garnet-hornblende-biotite gneiss.

Glacial Cover - Nil, to thin sandy till.

Topography - Well-drained area with low ridges. Depressions occupied by bogs.

Vegetation - Dense to open black spruce/jack pine woodland with scattered alder and birch.

1984 Survey (late July) - A traverse across this area, sampling at 200 m intervals, obtained one jack pine bark containing 950 ppb Au. A repeat analysis gave a value of 970 ppb Au. This sample was returned to Regina, loaded into a new vial and resubmitted for analysis six months later. The new analysis of 1000 ppb Au confirms the validity of the assay. The only other indications of possible mineralization are an associated arsenic content of 8 ppm and 4 ppm Se. Wild roses are present, indicating carbonates or calc-silicates, hence indirectly a favourable environment for gold.

1985 Survey (early June) - The vicinity of this occurrence was visited, but the anomalous jack pine was not relocated. Short of flagging every sample site it is difficult to find a tree from which only some bark scales have been removed.

Samples were collected at 50 m intervals for 300 m along three lines spaced 100 m apart, normal to the bedrock strike.

Gold data from alder twigs and conifer bark give no indication of mineralization. Arsenic levels in the conifer bark are above background (up to 14 ppm As), and antimony is locally enriched in jack pine bark (26 ppm Sb).

Comment - Other than slight enrichments of As and Sb, no confirmatory evidence could be found in this area to suggest the presence of gold.

Teneycke Lake/Upises Lake, 1 km east of Hwy 102 (UTM 505500E, 6142800N; NTS 74P-7) (Site 7, Fig. 1)

Bedrock - Granodiorite intruding a suite of intermediate to basic metavolcanics, and metasediments. Local pegmatite veins, and carbonate veins with traces of pyrite. Au, Ag and Cu reported from trenches north of the study area.

Glacial Cover - Nil, to sandy till probably no more than a few metres thick in valleys.

Topography - Well-drained hill of granodiorite flanked by metavolcanics and metasediments occupying valleys which are locally boggy.

Vegetation - Damp spruce woodland, to dry open woodland with jack pine on the granodiorite. More boggy to the south with dense alder growth.

1984 Survey (mid-June) - Southwest of Upises Lake gold levels in alder were anomalous at several sites, reaching a maximum of 110 ppb Au (Dunn, 1984, Fig. 9). Arsenic and antimony were enriched in spruce bark.

1985 Survey (early and mid-June) - Samples were collected from 50 locations between Teneycke Lake and Little Deer Lake (1.2 km to the south). Sample spacing was at 100 m intervals along several traverses normal to bedrock strike, and at 50 m intervals along two north-south traverses west of Upises Lake.

No alder sample contains an above-background concentration of gold, but no attempt was made to resample sites shown to contain anomalous gold the previous year. The survey was designed to try and define the southward extent of this anomaly. Jack pine bark, however, yields 180 ppb Au and 2400 ppb Au at sites 200 m west of Upises Lake. Five additional sites in this area contain over 20 ppb Au. Similarly, spruce bark contains 20 to 48 ppb Au at 13 of 20 sites sampled in the same vicinity. Arsenic (up to 14 ppm) and antimony (to 8 ppm) in jack pine show a weakly sympathetic correlation with gold. Molybdenum in alder shows isolated enrichments (e.g., 42, 48, 48 and 280 ppm) above a general background of 3 ppm.

Comment - There are indications of gold mineralization, but only from the conifer bark. The biogeochemical data indicate that near-surface gold mineralization in this area is localized, since no broad anomaly occurs other than generally elevated levels of arsenic and antimony.

Island Lake Pluton (UTM 550700E, 6202500N; NTS 73P-16) (Site 8, Fig. 1)

Bedrock - Junction between granodiorite of the Island Lake Pluton (to the west) and sheared zone of metavolcanics and metasediments adjacent to the McLennan Lake Thrust (Lewry, 1983; Thomas, 1984). No known mineralization.

Glacial Cover - Nil, to thin sandy veneer over granodiorite, thickening to sandy till (probably less than 2 m) over shear zone.

Topography - Low angle east-facing slope, becoming steep on approaching the granodiorite.

Vegetation - Mixed forest of spruce and poplar with alder. Boggy in eastern part of study area.

1985 Survey (late-July) - Alder samples were collected from 25 sites in this area by R. Cheesman, and prepared for analysis in the author's laboratory. They were of interest in that they were growing on soils recently found to contain up to 40 ppb Au.

Ashed alder twigs were found to contain remarkably high concentrations of gold (72 to 500 ppb), particularly for the time of the year (cf. Tables 1 and 2). Analysis of a second split of the sample that yielded 500 ppb Au gave an assay of 490 ppb Au. Fig. 4 shows the distribution of gold values in alder with respect to the underlying geology, and illustrates the close correspondence of the highest gold values with the subcrop of the contact between the granodiorites and the sheared metavolcanics and metasediments. Arsenic values are higher than usual for alders (up to 9 ppm As); bromine shows a weak positive correlation, and barium a weak negative correlation with the gold.

Comment - Biogeochemical indications are strongly favourable for the presence of gold, and complement the soil chemistry data.

Tower Lake (UTM 558000E, 6227000N; NTS 74A-1) (Site 9, Fig. 1)

Bedrock - Granodiorite and intermediate metavolcanic rocks. Elevated gold values are associated with a zone of irregular fractures encompassing silicification, carbonatization, pyritization and feldspathization; gold occurs to a lesser extent with biotite, chlorite, sericite and epidote (Netolitzky, in press). Grade is approximately 0.1 oz./ton Au. The study area is approximately 1 km south of the Byers Fault Zone, within which the Tower Lake gold deposit is located.

Glacial Cover - Single till unit less than 2 m thick that can

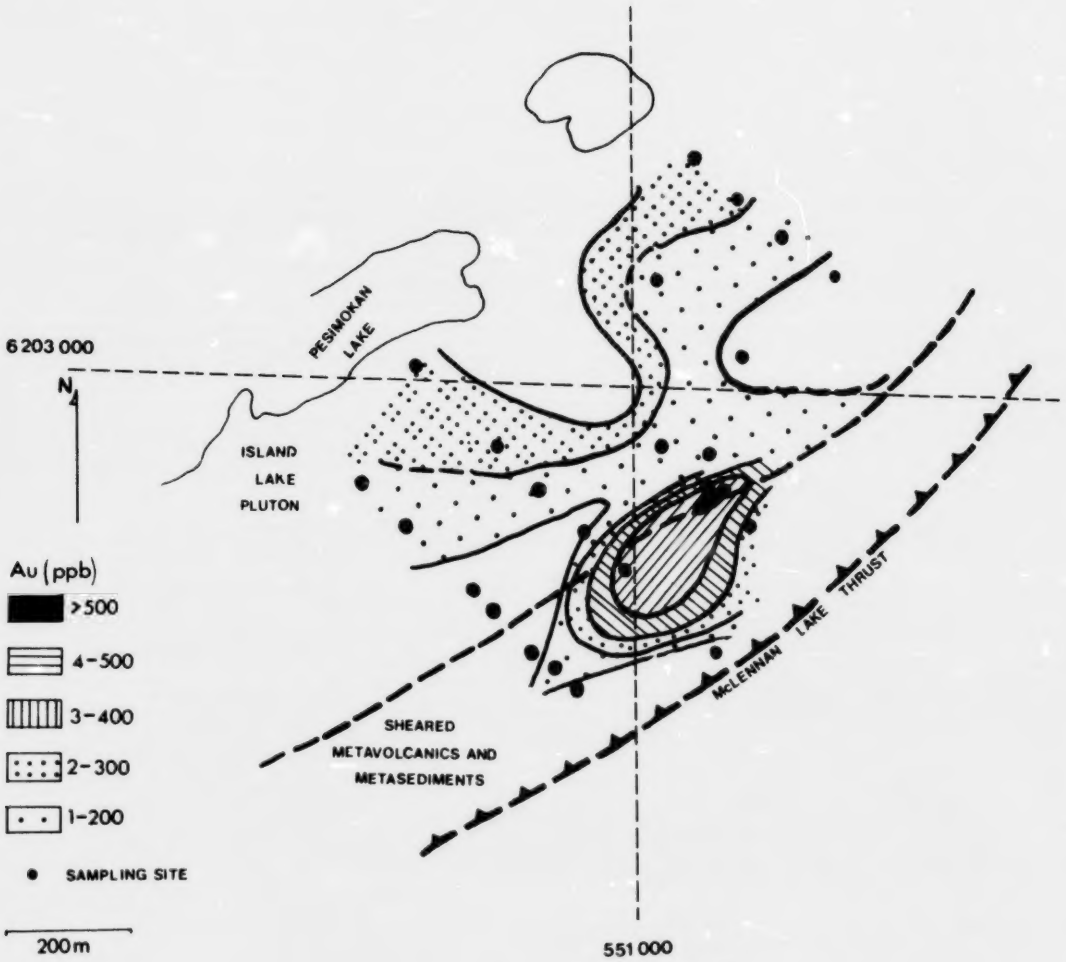

***Figure 4** - Gold in ashed alder twigs, Island Lake Pluton.*

be divided into lodgement and ablation facies. Locally there is an overlying till, and the entire survey area is blanketed with a veneer of fluvial sands and gravels, usually less than 1 m thick (Sopuck et al., 1985). Pits dug into the lower till commonly yield material with gold grains, up to about 100 grains per 7 kg sample (V. Sopuck, pers. comm.).

Topography - Sandy plain, locally boggy, with some gravelly ridges.

Vegetation - Damp to wet dense black spruce forest with alder and labrador tea. Ridges have dry open woodland with black spruce and jack pine.

1985 Survey (mid-June) - This area was selected for study because 1) the glacial stratigraphy is well known, 2) there is gold mineralization to the north and gold grains are dispersed in the till, and 3) soils do not reflect the chemistry of the underlying till owing to the cover of fluvial sands. Plant roots, however, may penetrate this

Table 7 — Gold Content of Vegetation from 1 km South of the Tower Lake Zone of Gold Mineralization.

Sample Type	*n*	*Au (ppb) in Ash*	
		Range	*Mean*
Alder Twigs	15	22 - 210	53
Black Spruce Twigs	22	14 - 140	44
Black Spruce Bark	22	12 - 62	35
Jack Pine Bark	14	9 - 30	19
Labrador Tea Stems	22	8 - 34	14

sand and indicate the presence of gold. One 900 m profile, parallel to and 1 km south of the Byers Fault Zone, was sampled at 50 m intervals, plus a few more sites of specific interest. Samples were taken (where available) of alder, labrador tea, spruce twigs and bark, and jack pine bark at each of 22 locations. Table 7 shows the range of concentrations obtained and the mean values. Alder twigs, spruce twigs and spruce bark proved the most responsive media to gold, and from these data it is evident that the area is enriched in gold (cf. Table 1). The relatively low gold content of jack pine bark is attributed in part to the occurrence of jack pine on the barren ridges of gravelly till, and to its exclusion from the wetter areas which are locally richer in gold.

Arsenic and antimony exhibit slight enrichment in the conifer barks, and molybdenum values range up to 36 ppm in alder twigs. Alder, too, is enriched in cobalt, cesium and the rare-earths at several sites. Bromine is depleted in all sample media.

Comment - The vegetation is successful in penetrating the veneer of fluvial sands and sampling the enhanced levels of gold in the substrate. In this environment biogeochemical methods are preferable to soil sampling.

Waddy Lake (UTM 568000E, 6229700N; NTS 64D-4) (Site 10, Fig. 1)

Bedrock - Round Lake granodiorite pluton intrudes intermediate and felsic metavolcanic rocks. Gold is associated with pyrite in the metavolcanics, and occurs as visible specks in quartz-filled fractures. Chloritization and carbonate alteration are present. Molybdenite, galena and several copper minerals have been is reported.

Glacial Cover - Scattered outcrop is surrounded by sandy till up to 5 m thick containing a gold dispersion train that trends southward from the gold-bearing EP Zone. This till is overlain by glacial lacustrine silts and clays of variable thickness - mostly less than 4 m, but locally as much as 11 m thick (Averill and Zimmerman, in press). A detailed study of the glacial stratigraphy in this area is given elsewhere (J. Campbell, this volume).

Topography - Moderate relief. Steep-sided ridges separated by boggy valleys.

Vegetation - Mainly spruce woodland and spruce bog. Poplar on some well-drained slopes, and small jack pine on outcrop.

1983 Survey (early August) - One hour was spent conducting an orientation survey (alder and spruce twigs) in an area where gold-bearing till, known as the Riddle Zone (Fig. 5), is exposed. From the 21 locations sampled it became apparent that several of the samples contained highly anomalous (up to 280 ppb Au) levels of gold (Dunn, in press).

1985 Survey (mid-June) - In the light of new information

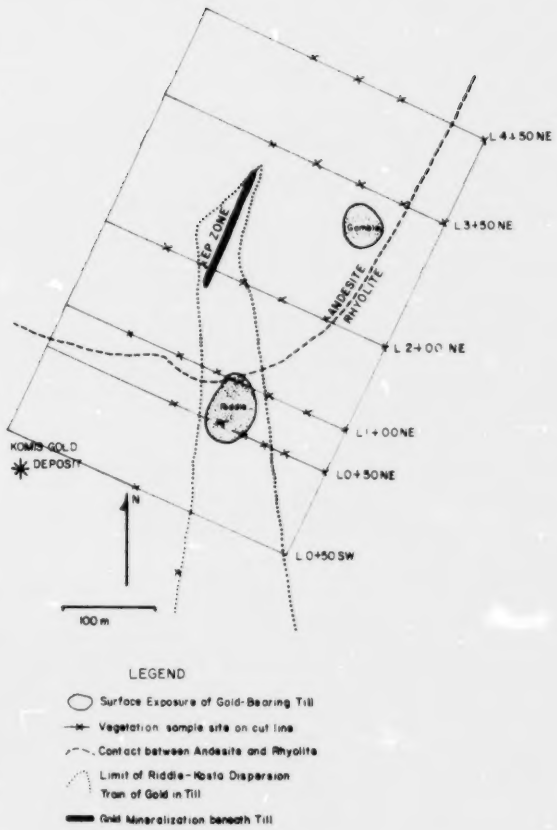

Figure 5 *- Geological contacts, gold mineralization (Komis and EP), and outline of gold-bearing tills, Waddy Lake area.*

on the glacial stratigraphy (Averill and Zimmerman, in press), several traverses were conducted in the Waddy area to compare the gold content of the vegetation with the glacial geology. Thirty-one sites were sampled along cut lines spaced 50 to 150 m apart, roughly normal to the southerly direction of glacial drift. Four alders sampled in 1983 and resampled in 1985 show moderately good reproducibility when allowance is made for the time of the year that samples were collected (i.e., lower concentrations in August). The alder values from the August 1983 survey and the June 1985 survey (in parentheses), are 6(23), 8(23), 25(23), 280(310) ppb Au.

Throughout the study area as a whole, alder twigs show only a weak response to gold in the substrate (10 ppb Au in the north, and 20 to 25 ppb Au in the south). However, data from the spruce bark show a strong response to gold, with concentrations up to 1800 ppb Au. Fig. 6 shows consistently high values east and south of the EP Zone. Contoured data indicate a dispersion direction from southwest to northeast (i.e., opposite to the regional direction of glacial movement). This may be related to groundwater movements.

Other data of note are high Mo values from alder twigs

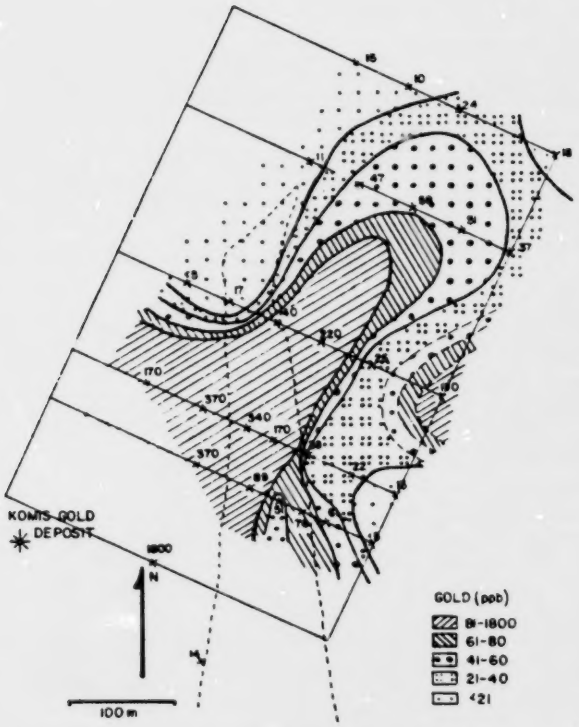

Figure 6 *- Gold in ashed spruce bark in relation to dispersion train of gold-bearing tills, Waddy lake area.*

(up to 230 ppm) and a tungsten value of 14 ppm in spruce bark from the site with 1800 ppb Au.

Comment - In view of the high level of exploration activity in the area, the possibility of contamination cannot be ruled out, particularly at the 1800 ppb Au site just southeast of the Komis deposit. However, if the high gold concentrations in spruce bark are a result of drilling contamination, it might be expected that the alders would show similar enrichment, and this is not the case. Furthermore, some bark samples from close to drill sites show no gold enrichment, whereas others in apparently undisturbed forest yield anomalous concentrations. Hence, it is believed that the gold in the spruce bark is not derived from contamination.

At the north end of the gold-in-till dispersion train (Fig. 5), the till lies beneath nearly 10 m of lacustrine silts and clays, resulting in depressed levels of gold (17 ppb Au - Fig. 6). It appears that even where the lacustrine sediments are as much as 4 m thick, the trees are strongly enriched in gold (e.g., sites on L0 + 50NE, where bark yields 76 and 61 ppb Au).

Another noteworthy feature of the data is the enrichment of gold close to the subcrop of the rhyolite/andesite contact.

It is concluded that the biogeochemical data from this area can be used as a guide to the location of auriferous tills and/or bedrock, and can assist in priorizing sites for overburden drilling.

Concluding Remarks

As the biogeochemical database increases, it becomes increasingly apparent that the biogeochemical response to gold mineralization varies from one location to the next. At Waddy Lake, spruce bark gives the sharpest response, whereas labrador tea and leather leaf have the highest gold concentrations at Star Lake. North of the Anglo-Rouyn mine, jack pine bark is the medium most highly enriched in gold. At Tower Lake and adjacent to the Island Lake Pluton, alder twigs are the most suitable sample media.

Although the patterns of gold and associated element uptake are varied and complex, it is evident that the biogeochemical method can provide a useful contribution to an exploration program. Clearly, in order to optimize effort and expenditure in the collection of vegetation, the sampling program should be tailored to the physical and geological environment. However, if gold mineralization is present, most of the common species of vegetation will absorb gold. Baseline data are now available for assessing the background levels of elements to be expected in vegetation of the northern forests.

Acknowledgement

I thank the many exploration companies whose properties I have visited this year for their helpful cooperation, and the SMDC for providing accommodation at their Star Lake exploration camp. Millrock Development Corp. supplied samples from the Island Lake Pluton area.

In particular I thank J. Lorenz, T. Kotzer, N. Richmond and D. Kasper for the first-class field and laboratory assistance which they provided this summer.

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Project 8502

Kisseynew Metallotect Geochemical Study

by G.R. Parslow[1] and J.W. Gaskarth[2]

Parslow, G.R. and Gaskarth, J.W. (1985): Kisseynew metallotect geochemical study; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

This project follows on four others which have investigated the geochemistry of the Amisk-type volcanics and associated rocks in the southeastern part of the Saskatchewan Shield, namely the East Amisk, Annabel Lake, Hamell Lake, and Hanson Lake projects (Parslow and Gaskarth, 1981, 1982a, 1982b, 1983, 1984, in prep.). Some of these studies delineated a major shear zone separating Amisk-type rocks from Kisseynew-type rocks along the line of Johnson Lake, Annabel Lake and Annabel Creek. This zone extends into Manitoba to the north of Embury Lake (Trout Lake Mine), through Tartan Lake and is probably represented at Puffy Lake by the mylonite zone of Zwanzig (1984). The studies have also shown that the rocks in the East Amisk area have ocean floor affinities, very different from those with arc-type affinities to the north (Flin Flon) and west (Hanson Lake). The recent copper-nickel discovery at Namew Lake lies due south and along the trend of these rocks.

There has been much discussion about the possibility that the Kisseynew rocks are the more highly metamorphosed lateral equivalents of the Amisk and Missi sequences (review by Moore, 1977; Bailes, 1980). A geochemical study of the numerous basic units in the Kisseynew rocks might throw some light on the possible equivalence to the Amisk volcanics.

In Manitoba, Robertson (1953) divided the Kisseynew into the Nokomis Group and the Sherridon Group, mainly on structural evidence. Gale (1981) refined the classification. Zwanzig (1984) correlated the Nokomis temporally with Amisk-type rocks, and the Sherridon with Missi. He also postulated a major unconformity at the base of the Sherridon. Gale and Ostry (1984) described a thin unit of variable volcanic and sedimentary rocks lying at the top of the Nokomis group directly beneath the Sherridon, and designated this unit the Kisseynew Metallotect because it contains massive sulphide deposits (e.g., Sherridon) and gold occurrences (e.g., Puffy and Nokomis Lakes).

The overall objectives of the present study are 1) to test the concept of the presence of a stratigraphically controlled metalliferous horizon, or horizons, within the Kisseynew Domain in Saskatchewan adjacent to the Manitoba border, and if such a horizon appears to exist, 2) to initiate a lithostratigraphic and lithogeochemical description and interpretation of the unit(s).

The initial methodology is to:

1) geologically map selected parts of the suspected metalliferous horizon(s) (i.e., the 'Kisseynew Metallotect') in Saskatchewan at appropriate detailed scales using geological parameters outlined by the Manitoba Geological Services Branch, and by any other appropriate indicators;

2) collect rock samples for geochemical study on selected traverses across the 'stratigraphy' of the metallotect;

3) undertake any necessary petrographic studies of the samples;

4) undertake whole rock, trace element and precious metal analyses of the samples;

5) use the data to establish, or otherwise, any possible stratigraphic controls for massive sulphide and/or gold occurrences within the metallotect;

6) use the data to establish exploration guidelines and target areas within the metallotect.

The above studies were intended to interface with a concurrent 1:20,000 scale regional geological mapping project in the same general area, but unfortunately, this project was abandoned due to unforeseen circumstances. With no regional mapping as back-up, the geochemical project was modified to concentrate more on the amphibolitic horizons of the presumed metallotect over a larger area, rather than detailed mapping of geological sections in limited areas. Consequently, step (1) above has not been covered in quite as much detail as was originally intended.

Much of the area under discussion has been mapped previously, as 15-minute quadrangles on a 1:63,360 scale, by Byers and Dahlstrom (1954), Cheesman (1956), Johnson (1966), Macdonald (1975) and Pyke (1961, 1965). A study of these maps shows that there are belts of hornblende gneiss, calc-silicate rocks and amphibolites that may represent 'metallotect horizon(s)' within the Kisseynew of Saskatchewan. Whether or not these belts separate the Nokomis and Sherridon subunits as they apparently do in Manitoba, and whether or not there is a major unconformity between the subunits as reported by Zwanzig (1984), is not apparent from the maps or from the work carried out this summer. K. Ashton's detailed work in the area (this volume), presently being done under contract to the Geological Survey of Canada, should clarify the identification of Nokomis- and Sherridon-type rocks in Saskatchewan.

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Project contracted to the University of Regina with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

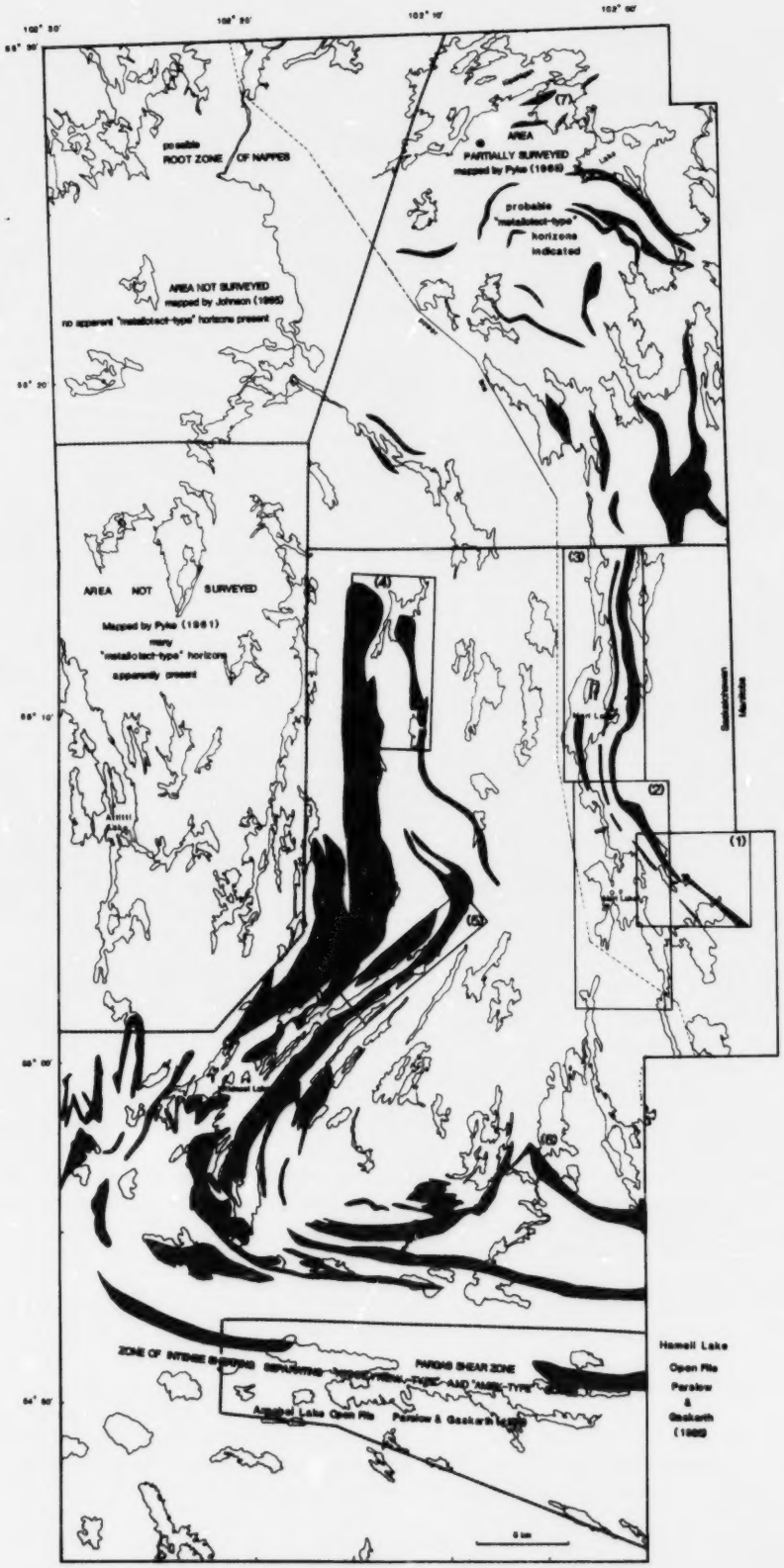

Figure 1 *- Location of study areas.*

The accompanying map of east-central Saskatchewan, is divided into five blocks. The southeastern block represents the main area of this study; within this block five areas and one traverse (Fig. 1) were studied in some detail (Figs. 2 to 6 show sample locations on a larger scale; the traverse is indicated as (6) on Fig. 1). Figure 1 also shows the location of 'metallotect-type' rocks with a stippled decoration. On the large-scale maps (Figs. 2 to 6) these rocks are denoted by an arrowhead pointing to the sample location. The northeastern block was not surveyed except for one small area on the south side of Kipahigan Lake (see location (7) on Fig. 1). Apparent 'metallotect-type' horizons, marked with a stipple, are more disrupted and less continuous than in the area to the south. The northwestern block was not visited; here the existing geological map (Johnson, 1966) shows no indication of any amphibolitic or basic gneisses or volcanic rocks which may be interpreted as 'metallotect'. The western area was also not visited; however, mapping by Pyke (1961) indicates the presence of a considerable number of units which are probably 'metallotect-type' rocks repeated by folding.

Eastern Mari Lake: Area 1

This area comprises a northwest trending and easterly dipping sequence of mixed supracrustal and mafic rocks abutting the western margin of a large, strongly foliated granodiorite body. Contained within the mafic rocks is the Dolly gold showing (Coombe, 1984).

The most distinctive rock type observed in the vicinity of the gold showing is a porphyritic basaltic rock (six or more metres thick) containing up to 40 percent subhedral plagioclase phenocrysts (up to 25 mm long) with some glomeroporphyritic clusters and partial flow alignment. We interpret this rock as a basaltic flow unit which has been preserved virtually undeformed. This unit thins considerably to the north and exhibits intense shearing on its western margin, to the extent that the original rock type is virtually unrecognizable. The eastern margin is unexposed and its southerly extension terminated by the east bay of Mari Lake. Close to the western contact are quartz-rich ultramylonitized rocks with 'quartz eyes' which are probably the flattened vestiges of disrupted quartz veins or pseudotachylites(?). Within the basalt there is a 300 mm 'layer' of heavily sheared fine-grained felsic rock, which is either a stratigraphic unit within the basalt or of tectonic origin. As noted above, this package of 'metallotect-type' rocks is bounded to the east by granodiorite while to the west of the sheared contact is a series of hornblende and biotite gneisses containing both foliated granitic layers and later unfoliated granitic material.

To the south, across the east bay of Mari Lake and along strike from the Dolly showing, a zone of mafic rocks was identified by Macdonald (1975). A traverse along this unit (Fig. 2) identified the presence of hornblende gneisses grading to amphibolite in places. At one locality, a coarse-grained plagioclase/hornblende rock and a coarse-grained honrblende/garnet/light brown biotite (phlogopite?) rock occur together with some sulphides (mainly pyrrhotite). These rocks are interpreted as relict gabbroic and/or ultrabasic rocks. At the extreme south end of the traverse some calc-silicate horizons crop out in close association with the more typical 'metallotect-type' rocks. Evidence of shearing is commonplace throughout this generally mafic unit.

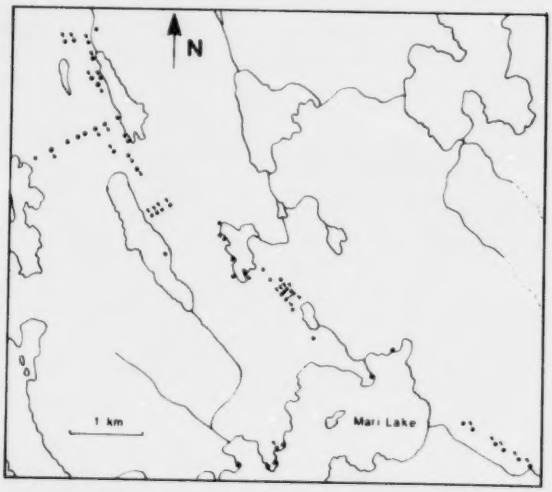

***Figure 2** - Sample locations, eastern Mari Lake (Area 1).*

The northern continuation of the 'metallotect-type' rocks is terminated, possibly by shearing out, about 1 km north of the Dolly showing. However, a series of traverses further north clearly identified a zone of hornblende gneisses and a few units of amphibolite, trending in the same direction and to the northwest of the showing. At two localities the rocks are very similar to but more deformed than the porphyritic basalt. Since many of these more northerly outcrops (some of which have been trenched) are pyritic, rusty weathering and contain rare chalcopyrite, we consider that this sequence of rocks represents the continuation of the Dolly showing rock package (i.e., the 'metallotect') north of the shear. The sulphide mineralization is confined to the eastern margin of this northern package.

The only other 'metallotect-type' rocks observed in Area 1 were encountered on two traverses about 1.5 km west of the packages described above, consisting of thin units of hornblende gneiss and amphibolitic gneiss with some pyrite and chalcopyrite.

Central Mari Lake: Area 2

In Area 2, 'metallotect-type' rocks are found only to the

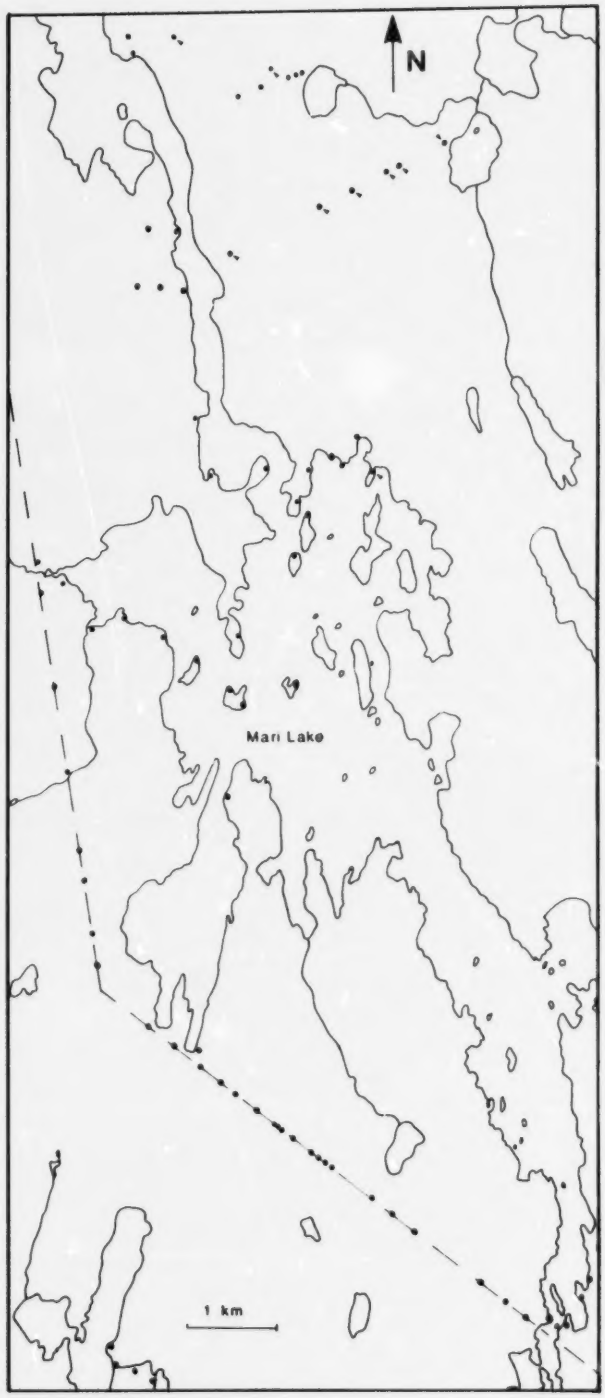

Figure 3 - *Sample locations, central Mari Lake (Area 2).*

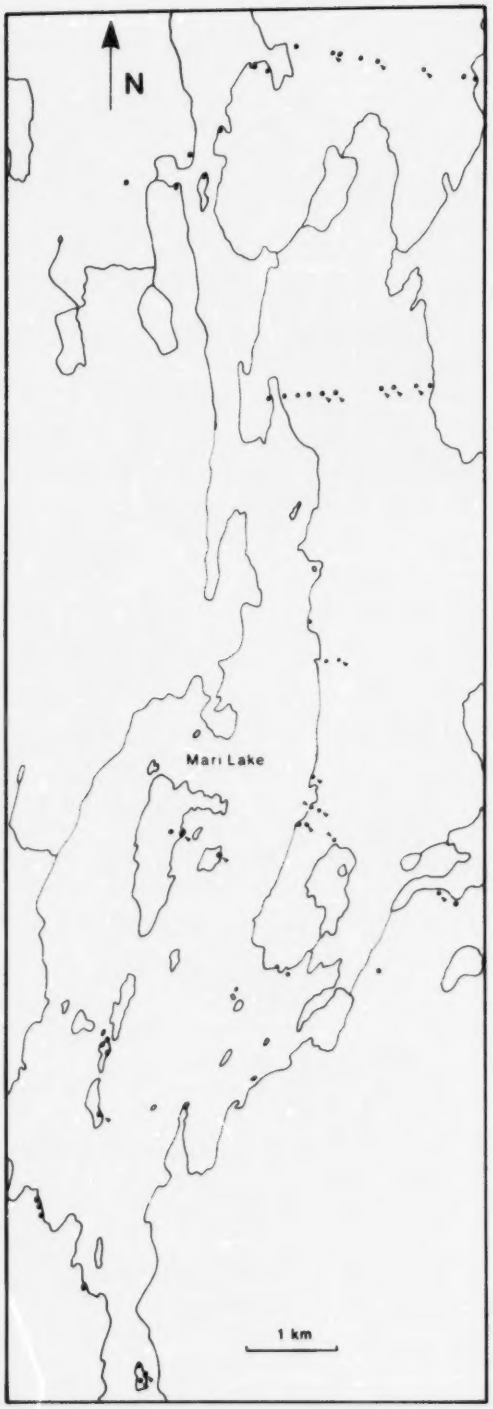

Figure 4 - *Sample locations, northern Mari Lake (Area 3).*

east of the northernmost narrows of Mari Lake (Fig. 3). These rocks lie in two zones, a thin westerly unit and a thicker eastern unit, and appear to be the northern continuation of the units recognized in Area 1. The dominant rock type is hornblende gneiss with sporadic amphibolite units. Garnets are common but irregularly distributed and in places give the rocks a 'knobbly' appearance on weathered surfaces. Traces of sulphides are present in some outcrops. Thin calc-silicate interlayers occur in the sequence. The extreme northern portion of the eastern 'metallotect-type' unit is considerably thinned.

Northern Mari Lake: Area 3

In Area 3 the two 'metallotect-type' horizons are believed to continue northwards along the eastern side of the lake (Fig. 4). However, a third horizon is found on islands in the centre of the lake. The two easterly horizons consist of hornblende gneisses, amphibolites and thin calc-silicate interlayers as described above, but no well-preserved igneous fabrics were observed. At one locality, on the eastern edge of the larger of the two horizons, chalcopyrite and associated malachite staining were found.

The third horizon consists essentially of medium- to coarse-grained amphibolite, with up to 5 percent bronze mica (possibly phlogopite), which varies from massive in the south to a less homogeneous and more gneissic rock in the north. The coarser rock in the southern section is tentatively identified as a gabbro with sheared margins.

The following inferences can be drawn from the Mari Lake traverses:

1) 'Metallotect-type' rocks occur in the Kisseynew rocks of eastern Saskatchewan and correlate with those described in Manitoba.

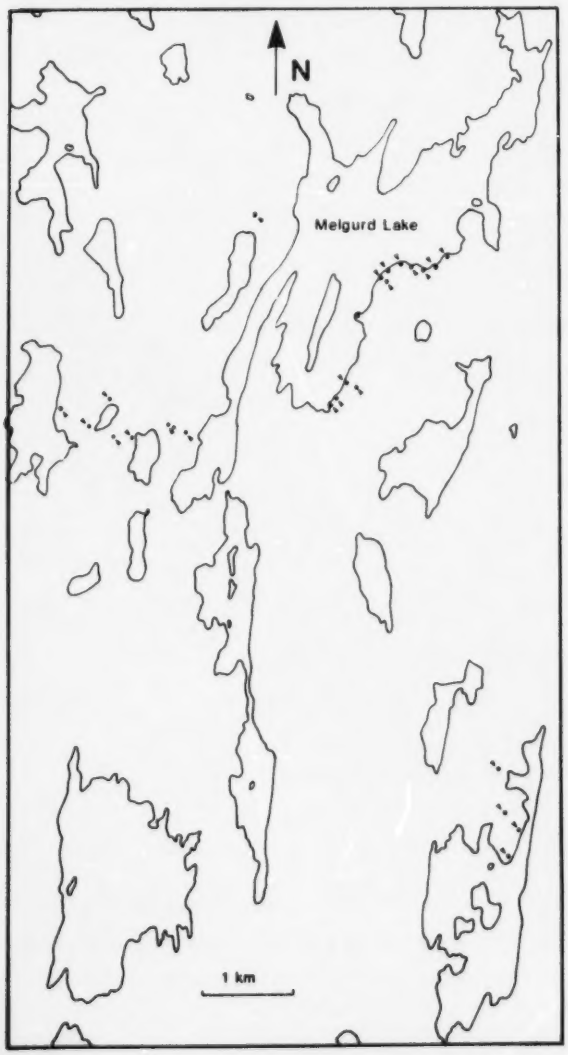

Figure 5 - *Sample locations, Melgurd Lake (Area 4).*

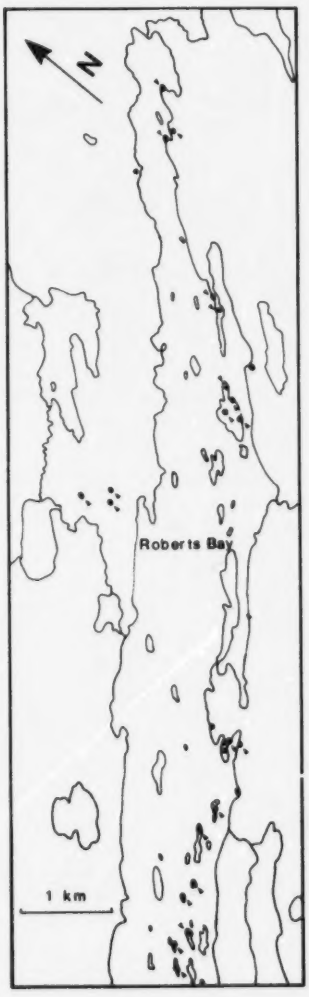

Figure 6 - *Sample locations, Roberts Bay, Wildnest Lake (Area 5).*

2) The metallotect package is very varied, ranging from gabbros and basalts, through amphibolites and calc-silicates, to hornblende gneisses. Although deformation has destroyed most igneous fabrics, enough palimpsest features are recognizable to identify the package as igneous, containing both extrusive and intrusive rocks.

3) Although the Manitoba metallotect is shown as a single unit or zone, the present work identifies at least three units. Whether these units are indeed stratigraphically discrete or are structural repetitions of a single unit is not clear in the Mari Lake area.

4) As in Manitoba, gold and base metals are associated with the package.

Having identified previously mapped amphibolites and/or hornblende gneisses in the Mari Lake as 'metallotect-type' horizons, it was decided to examine some other areas that, according to existing geological maps, contain similar rock types. The two main areas selected were Melgurd Lake (Area 4) and Roberts Bay on Wildnest Lake (Area 5). Limited investigations were also done on Little Mari Lake (Location 6), the west side of Wildnest Lake and the northwest part of Kipahigan Lake (Location 7).

Melgurd Lake: Area 4

The southeastern and western sides of Melgurd Lake are occupied by large patches of mafic rock mapped by Cheesman (1956, Unit 5) as amphibolite and (to the west) calc-silicate gneiss. Traverses this summer (Fig. 5) showed that these rocks form an interlayered sequence, in places containing pyrite and/or chalcopyrite. The similarities between this package and those observed at Mari Lake leads us to believe that these rocks also represent a 'metallotect-type' horizon. The presence of considerable carbonate-bearing material in association with amphibolites and hornblende gneisses does not detract from the concept of the 'metallotect' being largely volcanogenic in origin.

On the eastern side of the lake, an extensive area of coarse-grained basic rock, in some places containing specks of chalcopyrite, was observed. This rock is poorly foliated and consists largely of amphibole and feldspar with variable quantities of either biotite or garnet. Primary igneous textures, such as large feldspar phenocrysts (up to 30 percent of the rock), are present in places. We consider that these rocks represent a large gabbroic intrusion. Observed contacts are strongly sheared and the original 'gabbroic' texture has been destroyed, the result being a banded hornblende gneiss. A brief visit to a small lake about 4 km south indicated the presence of virtually identical gabbroic rocks. It is considered likely that the Melgurd lake gabbroic body extends at least some 6 km. Moreover, airphoto and previous mapping information lead us to postulate that this unit extends a further 10 km to the southeast. The elongate shape of this gabbroic body is typical of previously described 'metallotect' horizons.

Roberts Bay: Area 5

This area was visited to investigate the northeast-trending zones of amphibolites, hornblende gneisses and calc-silicates mapped by Cheesman (1956). The rocks encountered constitute two zones (Fig. 6), the easternmost of which comprises interlayered amphibolitic and calc-silicate rocks very similar to those present on the west side of Melgurd Lake. The other zone is largely composed of calc-silicate rocks. The conclusion is reached that these rocks also form one or more 'metallotect' horizons.

Brief visits further to the west on Wildnest Lake also encountered calc-silicates and amphibolites which probably also represent other possible 'metallotect' horizons.

Although relict igneous fabrics are uncommon, the overall impression is that these rocks in the western part of the main area of study are volcanogenic.

Little Mari Lake: Location 6

A traverse across the hornblende gneiss unit of Byers and Dahlstrom (1954) at the south end of Little Mari Lake encountered units of amphibolite and calc-silicate, and one thick (10 m) hornblendite layer within the hornblende gneisses. The sequence is very similar to others described above and thus the hornblende gneisses are interpreted as probable 'metallotect' horizons.

Kipahigan Lake: Location 7

A study of some localities of the diopside - calc-silicate granulite and hornblende gneisses of Pyke (1965) in the northwestern part of Kipahigan Lake was undertaken to see if they had any characteristics typical of 'metallotect' horizons further south.

It was observed that the area is of much higher grade (Rees, 1980) and the incipient melting and breakdown of rock units is much in evidence. However, some exposures do exhibit remnants of basic rocks containing sulphides, such as hornblendites, that have survived the pervasive granitization common throughout the area. It is concluded that 'metallotect-type' horizons exist here (as outlined in Fig. 1) but that their lateral continuity has been disrupted.

The Kisseynew Metallotect - An Interpretation

As a result of the 1985 field work and a study of the available literature, the following points are considered important in the development of any evolutionary model for the region:

1) 'Metallotect-type' rocks are variable and occur in thin belts, but all are readily explained as being volcanogenic.

2) The multiplicity of 'metallotect-type' units is apparent in all areas investigated.

3) Kisseynew-type rocks, including 'metallotect-type' horizons, are terminated in the south by a major east-west shear zone.

4) Amisk-type rocks lie to the south of the east-west shear zone.

5) Rocks south of the shear zone are generally of upper greenschist facies, while to the north the grade increases abruptly across the shear and reaches hornblende granulite facies just northwest of Kipahigan Lake (the northernmost part of the present study area).

6) Foliations throughout the Kisseynew rocks in the area studied have shallow dips (values less than 20° are common). Pearson (1972) suggested that nappe-like folds are present in the Wildnest-Tyrrell Lakes area, and Macdonald (1975) identified recumbent isoclinal and nappe-style folding in the Mari Lake area.

7) Outcrop patterns of 'metallotect-type' rocks on published maps, around Wildnest and Attitti Lakes, look like refolded isoclinal folds (F_1). Such extensive isoclinal folding has not been documented in either the Amisk-type rocks or in the La Ronge volcanic belt.

8) The Flin Flon and Lynn Lake volcanic belts are separated by the bilaterally symmetrical gneisses of the Kisseynew Domain and its central granitoid complex (MacRitchie quoted by Moore, 1977). This domain thus appears to be anticlinorial.

9) Late Archean to early Proterozoic dates have been obtained from the Sahli Gneiss dome in the Hanson Lake block (Bell and Macdonald, 1982; Van Schmus et al., 1985) and also in the McMillan Point granite nearby (Bickford and Van Schmus, this volume). Kisseynew-type gneisses occur beneath Amisk-type volcanic rocks in the Jackpine Lake anticline just south of the above dated basement (Gaskarth, 1967, 1971).

10) A recent review of available Rb-Sr data for the La Ronge and Flin Flon Domains (Watters and Armstrong, 1985) documents some metasedimentary rock isochron points plotting above the 1900 Ma crustal growth curve which may be the result of an older basement component in these rocks.

11) Kisseynew-type gneisses east of the La Ronge volcanic belt have constant facing directions to the west (Sibbald, pers. comm., 1985).

12) The east side of the La Ronge volcanic belt is terminated by a major shear zone (Lewry, pers. comm., 1985).

It is proposed that the above observations can be explained most simply by having the Kisseynew stratigraphically beneath the Amisk and at a much deeper level in the crust at the onset of the Hudsonian Orogeny. A significant thermal event caused a major uplift of the Kisseynew, with concomitant nappe emplacement, resulting in the observed gross bilateral symmetry of the Kisseynew Domain. The higher level rocks above the thermal uplift would not be deformed in the same style, would be disrupted, and would be preserved only at the margins of the high-grade nappe complex and separated from it by major shear zones.

The major implications of this model are:

1) The Flin Flon - Snow Lake and La Ronge - Lynn Lake volcanic belts are the disrupted fragments of the products of a single volcanic event. This simplifies any plate tectonic model in that only one destructive plate margin is required rather than two contemporaneous ones.

2) The multiplicity of metallotect horizons can readily be explained by repetition, a consequence of the F_1 nappe event.

3) Considerable lateral translation of Kisseynew-type rocks has occurred, and the contact zones between the volcanics and the high grade gneisses have great tectonic significance.

Economic Implications

The above model has several important implications for the mineral potential of the region:

1) Mineralization within the metallotect horizons does not correlate with mineralization in the lower grade volcanic sequences (e.g., Amisk-type volcanic rocks).

2) Shear zones separating the high-grade gneisses from the lower grade volcanics have great potential for gold mineralization. We note, tentatively, that the east-west shear zone through Annabel Lake might extend across the Tabbernor Zone into the Wapawekka Lake area (cf. Macdonald and Broughton, 1980).

3) The geochemistry of the lower grade volcanic rocks indicates that there are both arc- and ocean floor-type environments. Thus, at least two types of massive sulphide deposit can be expected (e.g., Flin Flon-type vs. Namew Lake-type).

4) Significant gold occurrences, which are found in all three of the above environments, appear to be structurally controlled and, although some are apparently stratabound, they are probably epigenetic.

5) The Attitti Lake and Scimitar Lake complexes (Macdonald, 1981), which contain many apparent metallotect horizons possibly due to nappe-generated repetitions of a single unit or units, are deserving of more attention.

Acknowledgements

We wish to acknowledge the help of L. Schick, D. Riley and M. Kolebaba for the high standard of their field assistance. We are also indebted to J. Pearson (Resident Geologist, Creighton) and J. Siryj for their help and hospitality.

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Saskatchewan Shield Geochronology Project: Rb-Sr Studies, 1985

by Keith Bell[1] and Michael Bikerman[2]

Bell, K. and Bikerman, M. (1985): Saskatchewan Shield geochronology project: Sr-Rb studies, 1985; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

This year's work concentrated on 1) completing analyses on whole rock and mineral phases from the 'Mine granites' in the Beaverlodge area, and 2) attempting to date the Sahli granite by the Sm-Nd method.

Previous attempts to obtain good whole rock Rb-Sr isochrons from the Athona, Box and Frontier bodies (the 'Mine granites') met with little success (Bell and Blenkinsop, 1982, 1983). The data from each of these bodies show pronounced scatter and it is difficult to obtain even an approximate date from most. This contrasts with the good whole rock Rb-Sr isochrons obtained from two nearby bodies, the Cameron Island and Mackintosh Bay granites, which have now yielded dates of 2010±70 Ma and 2020±20 Ma respectively. By excluding several data points from the Frontier granite, it was possible to construct an acceptable isochron that corresponds to a date of 1760±100 Ma, a figure interpreted as a time of resetting during the Hudsonian metamorphism.

In the light of recent field work by Sibbald, new evidence became available that made it possible to re-interpret the whole rock isotopic data from the Mine granites. The Mine granites, a series of lenticular sheets, are considered by Sibbald (1984) and earlier workers to be the product of feldspathization of sedimentary material. This model is certainly consistent with the scatter of the data observed for each of the individual Mine granites. In order to smooth out any isotopic differences within an individual body, average values were calculated for the present-day $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios for each of the three Mine granites. Only two points out of a total of twenty-two were excluded from the calculations. If the three average data points are used, an isochron can be obtained that corresponds to a date of approximately 2077 Ma and an initial $^{87}Sr/^{86}Sr$ ratio of 0.713. This date is fairly close to the model age of 2050 Ma quoted by Bell and Blenkinsop (1982) for the Athona granite and similar to the dates obtained from both the Cameron Island and the Mackintosh Bay granites.

Our preliminary interpretation of the data from the Mine granites encompasses a model that involves metasomatism of supracrustal sedimentary material between 2000 and 2100 Ma ago, an event that could have been accompanied by fluid activity responsible for the gold mineralization in the area. We attribute the scatter of the individual data points from the Athona, Box and Frontier granites as being due to either inherited isotopic heterogeneities or open-system behaviour. Some new whole rock chemical analyses show that the Frontier granite has an average SiO_2 value of 83 weight percent. This, coupled with the chemical analyses quoted by Sibbald (1984), suggests involvement of silica-rich sedimentary rocks during formation of some of the Mine granites.

New data from feldspar separates from the Mine granites partially support the 2024 Ma event. Feldspar data, however, from the Box granite also show that these bodies have been affected by later thermal overprinting. A date of 1740±220 Ma clearly shows later disturbances during the Hudsonian orogeny in the Box granite.

Preliminary whole rock Sm-Nd work on the Sahli granite, previously dated at 2424±30 Ma by the Rb-Sr method, yielded a date of 2420±240 Ma and an initial $^{143}Nd/^{144}Nd$ ratio of 0.5093±0.0002. The large uncertainties are due to the restricted spread in the Sm/Nd ratios of the samples analyzed to date. Two mineral whole rock Sm-Nd isochrons were obtained from two separate samples of the Sahli granite. One of these, a garnet-amphibole whole rock Sm-Nd isochron, yields a date of 1703±32 Ma, while the other, a two-point garnet whole rock date, gives a broadly similar value of 1770±15 Ma. Both dates show that the Sahli granite has been affected by later Hudsonian overprinting. These Sm-Nd dates are some of the first to be obtained from the Churchill Province.

Decay constants used are:

$$^{87}Rb = 1.42 \times 10^{-11}\,yr^{-1}$$
$$^{147}Sm = 6.54 \times 10^{-12}\,yr^{-1}$$

All errors have been quoted at the two-sigma level.

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Project contracted to Carleton University with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Project 8525

Neodymium, Strontium and Lead Isotope Geochemistry Project

by Kenneth D. Collerson[1] and John F. Lewry[1]

Collerson, K.D. and Lewry, J.F. (1985): Neodymium, strontium and lead isotope geochemistry project; *in* Summary of Investigations 1985, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 85-5.

Sample collection was completed in June 1985 for a multi-system (Nd, Sr, Pb) whole-rock and mineral isotopic study of selected suites of rocks from critical areas in the Saskatchewan part of the Thelon segment of the Trans-Hudson Orogen (Lewry, 1984; Lewry et al., 1985). Initial analytical work on selected samples will be carried out during November, 1985 at the Department of Terrestrial Magnetism, Carnegie Institution, Washington, D.C.

This study is intended to complement the U-Pb zircon dating program currently being undertaken at the University of Kansas (Bickford and Van Schmus, this volume). It is expected to provide information concerning the timing of crust-mantle separation events within the Trans-Hudson Orogen, the isotopic character of the contemporary mantle, the distribution of Archean and reworked Archean crustal components, and an evaluation of the scale of diffusion during isotopic homogenization in response to tectonothermal activity. It will eventually include a study of Sm-Nd isotope systematics on a mineralogical and whole-rock scale at different grades of metamorphism, and is expected to yield Sm-Nd radiometric ages of some rocks (primarily basic-ultramafic types) which are not amenable to the U-Pb zircon dating method.

Recent radiogenic isotope studies of Precambrian basement terrains in North American and other cratonic blocks (DePaolo, 1981; McCulloch and Wasserberg, 1978; Patchett and Bridgwater, 1984) allow conclusions to be drawn regarding the age of initial separation of crustal material from the mantle. In the case of Lower Proterozoic orogenic terrains, they permit distinction between regions underlain by Archean continental basement which have been reworked during Early Proterozoic orogeny, and terrains which represent accretion of new crustal material as, for example, oceanic magmatic arcs. Reconnaissance isotopic data for the eastern part of the Thelon Segment in Saskatchewan (Chauvel et al., in press) indicate that terrains east of the Wathaman Batholith represent accretion of primitive Early Proterozoic crustal components, with little involvement of older Archean crust. This contrasts sharply with terrains to the west of the Wathaman Batholith, which on geological evidence are known to be mostly underlain by variably reworked Archean continental basement. Such data impose important constraints on models of Early Proterozoic crustal evolution and orogenic mechanisms.

[1]Department of Geology, University of Regina. Project contracted to the University of Regina with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Phases of this research were also supported by NSERC grants A0594 to K.D.C. and A7426 to J.F.L.

Sample Descriptions

Samples collected this summer are summarized below. Approximate specimen locations are given in brackets. Localities also sampled for U-Pb zircon dating by Bickford (Bickford and Van Schmus, this volume) are asterisked.

Western Craton

HUD85-1* (narrows between Wasekamio and Turner Lakes): Junction Granite; a moderately foliated, coarse megacrystic monzogranite.

HUD85-2* (southwest end of Hill Island, Wasekamio Lake): Blue quartz gneisses; partly retrograded granulite facies dioritic-granodioritic gneisses cut by amphibolite dykes. Both lithologies were sampled.

HUD85-3* (on winter road 1000 m west of west shore of Wasekamio Lake): Banded aplite/pegmatite, intrusive into older retrograded granulites.

HUD85-4 (on Clearwater River, south of Fournier Lake): Layered anorthosite-leucogabbro/norite. Six samples were collected from different parts/layers of the body.

HUD85-7 (northwest end of Fournier Lake): Layered anorthosite-leuconorite-pyroxenite (this locality was included in the 'granulite gneisses' of Scott, 1979). A suite of five samples was collected, ranging from pyroxenite to gabbro/norite to anorthosite.

HUD85-8* (peninsula on east shore of north arm of Fournier Lake): Xenolithic rafts of granulite facies migmatitic tonalitic gneiss within leuconorite-anorthosite host rocks. Both the xenolithic gneiss and the norite were sampled.

HUD85-9* (island in central part of Careen Lake): Augen granitic gneiss with intense to mylonitic (Hudsonian?) planar/linear fabric.

HUD85-10* (small island at southwest end of Careen Lake): Less tectonically overprinted heterogeneous gneisses apparently cut by boudinaged pyroxenitic dykes. Both tonalitic gneiss and pyroxenite were sampled.

Mudjatik Domain

HUD85-5* (island in north part of Dipper Lake): Uniform charnockitic granite.

HUD85-6* (southeast shore of Dipper Lake): Grey tonalitic orthogneiss.

HUD85-12* (southeast shore of Jim Lake): Orthopyroxene-bearing felsic gneiss with composite fabric.

HUD85-14 (southwest shore of Porter Lake): Laminated amphibolite and ultramafic granulite with orthopyroxene-bearing neosome 'sweats'; probable metavolcanic assemblage.

HUD85-15* (north end of Segment Lake): Finely laminated felsic granulites within mafic (metavolcanic?) gneiss unit; probable felsic-intermediate volcanics.

Wollaston Domain

HUD85-16* (narrows north of Horton Island, Nekweaga Bay, southwest Wollaston Lake): Horton Island Granite; post-tectonic biotite leucogranite.

HUD85-17* (south Wollaston Lake shoreline, south of Brandser Island): Slightly megacrystic pink granite; possible anatectic derivative of upper Wollaston Group meta-arkoses.

HUD85-18* (small island in northern part of Compulsion Bay): Within the largely Archean Johnson River basement inlier. This outcrop shows older grey tonalitic and pink augen gneisses with some layered supracrustal amphibolite inclusions, apparently cut by later pink granitic gneiss. In one locality, an early mafic dyke is apparently intrusive into the older gneiss assemblage. Samples of the augen gneiss, mafic dyke and later pink gneiss were collected.

HUD85-19 (island south of locality 18): Johnson River Inlier; mafic dykes cutting grey augen gneiss with later pink granitic gneiss. The older augen gneiss was sampled.

HUD85-20* (northeast end of Linn Island, south Wollaston Lake): Augened pink granitic gneiss with amphibolite gneiss supracrustal inclusions; part of the Linn Island basement inlier. Both augen gneiss and amphibolite were sampled.

HUD85-21 (northeast end of largest of Sandy Islands, central Wollaston Lake): Sandy Islands Gabbro; little deformed, rhythmically layered gabbro-diorite, with local pyroxenitic and syenitic phases and both felsic and mafic xenoliths. Five phases of the pluton and one of the xenoliths were sampled.

Peter Lake Domain

HUD85-22 (small island east of Crane Island, MacLean Bay, north Reindeer Lake): Hornblende gabbro and gabbroic pegmatite cut by porphyritic diabase dykes. Suites were collected from fine-grained melagabbro, coarse pegmatitic gabbro phases and the diabase dykes.

HUD85-23 (island east of locality 22): Rhythmically layered gabbro with clinopyroxenite nodules (derived from early cumulus phases?) cut by feldspathic diabase dykes. A sample of the clinopyroxenite was collected.

HUD85-24* (shoreline southwest of Crane Island, north Reindeer Lake): Well-layered hornblende gabbro with patchy pegmatitic phases. Both ultramafic hornblendite and anorthositic cumulus layers are present locally within a layered gabbro/melagabbro/porphyritic gabbro body with later irregular hornblende pegmatite phases. Six sample suites of various phases were collected.

HUD85-25* (shoreline southeast of locality 24): Complex outcrop of discontinuously banded augen granitic gneisses, which include mafic gneiss paleosome and are cut by leucocratic granitic gneiss. This complex is cut by mafic dykes, later pink aplite sheets and finally by xenolithic granodiorite. Samples of all phases but the mafic dykes and aplites were collected.

HUD85-26: (shoreline west of Patterson Island, northwest Reindeer Lake): Coarse-grained leucogabbro, displaying well-developed 10 cm scale rhythmic layering.

Geological Comments

The primary objective of the summer's work was sample collection. However, some revisions of previous geological interpretation and a number of additional observations were made in the course of outcrop examination. The most important of these are summarized below:

1) Rocks previously designated 'granulite gneisses' by Scott in the Fournier Lake area of the Western Craton (sample localities 7 and 8) were identified as only moderately deformed orthopyroxene-bearing anorthosites and leuconorites displaying ubiquitous well-developed primary igneous layering and local mafic to ultramafic cumulate layers. Pyroxenitic erratics observed in the same localities may derive from comagmatic phases exposed *in situ* elsewhere. Semicontinuous, freshly burnt outcrop extending eastward from Fournier Lake to the mapped western boundary of the anorthosite body (locality 3) appears to comprise similar layered plutonic rocks, suggesting that a continuous, major, layered, anorthosite-norite body extends at least 5 km farther west than this boundary. Other rocks similarly designated 'granulite gneisses' in previous mapping elsewhere in this part of the Western Craton, extending northwestward to Lloyd Lake, may require similar reinterpretation, at least in part. The existence of such a major layered plutonic complex in this area has evident economic implications for platinum-group element exploration.

2) Re-examination of predominantly mafic (amphibolitic and pyribolitic) gneiss zones in the Mudjatik Domain supports previous interpretation of these rocks as being derived from metavolcanic rather than intrusive protoliths. Their absence in the main Wollaston Group succession to the east suggests that they may be of Archean rather than Early Proterozoic age (cf. Lewry and Sibbald, 1980).

3) Detailed examination of outcrops within the Johnson River inlier (localities 18 and 19) revealed more complex lithological relationships than hitherto described in the reconnaissance mapping. An early heterolithic gneiss assemblage (possible Archean granitoid basement?) is cut by mafic dykes, which are in turn cut by late granite phases. The dykes may possibly represent late Archean - early Proterozoic inter-orogenic intrusions, predating Early Proterozoic sedimentation and Hudsonian thermotectonism. A similar relationship was documented in the 'older gneiss' terrain in the northeastern part of the Peter Lake Domain, suggesting possible continuity of older basement material between this and the Wollaston inliers.

4) In previous work (eg. Lewry et al., 1980), hornblende in the Peter Lake gabbroic bodies was generally interpreted as metamorphic in origin. However, relationships seen in very clean large outcrops around north Reindeer Lake (e.g., localities 22, 23, 24, 26) suggest that these rocks are essentially unmetamorphosed primary hornblende-bearing gabbros derived by crystallization of 'wet' magmas. Primary textural relations are well preserved. In some localities, irregularly distributed, totally undeformed 'gabbroic pegmatite' segregations contain large bladed hornblendes that are unlikely to be the result of metamorphic recrystallization. Elsewhere, large individual hornblende crystals form cumulate layers at the base of graded units. There is generally little field indication of significant metamorphic modification, either of primary textures or mineralogy.

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Preliminary U-Pb Age Data For The Trans-Hudson Orogen in Northern Saskatchewan: New And Revised Results

by M.E. Bickford[1] and W.R. Van Schmus[1]

Bickford, M.E. and Van Schmus, W.R. (1985): Preliminary U-Pb age data for the Trans-Hudson Orogen in northern Saskatchewan: new and revised results; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

During the past year we have continued to work on obtaining precise ages from zircons separated from rock samples in the Trans-Hudson Orogen in northern Saskatchewan. The locations and descriptions of samples collected during the 1983 field season were given by Bickford et al. (1983) and the first set of preliminary age data have been given by Bickford et al. (1984) and Van Schmus and Bickford (1984). Additional sampling during the 1984 field season included collecting by three University of Kansas graduate students, Steven R. Persons, Christina Livesey, and Michael T. Meyer.

In this report we will give an updated list of zircon ages obtained, including a discussion of results from seven previously unanalyzed samples, and revisions of the ages of three samples previously reported. Additionally, we will describe new sampling done during the 1985 field season in collaboration with J.F. Lewry and K.D. Collerson of the University of Regina.

The data reported here were determined in the Isotope Geochemistry Laboratory of the University of Kansas by standard methods of isotope dilution and mass spectrometry. The decay constants used are those of Steiger and Jager (1977). Where uncertainties in the ages are given, they were calculated by the methods of Ludwig (1980) and are 2-sigma values. The data presented should be considered as preliminary and may be revised before final publication. Revisions will be made in some cases because additional fractions of zircon will be analyzed. As discussed below, additional processing of zircon fractions by air abrasion on some samples (Krogh, 1982) or special hand-picking of selected materials provides new information which may change interpretation of the data.

The results of our zircon age determinations are given in Table 1. Some of these results were given in last year's report (Van Schmus and Bickford, 1984).

New Results

Locations and references for 1983 samples are given in Bickford et al. (1983).

HUD 83-12 Wykes Lake Pluton: This sample of granodiorite was collected from the north end of Wykes Lake in the Glennie Lake Domain. It yields an age of 1844±12 Ma on the basis of analysis of four zircon fractions. This result is similar to the ages of 1860 to 1840 Ma obtained for most of the plutons in the La Ronge Belt.

HUD 83-13 Eyahpaise Pluton: This sample is granodiorite to tonalite from the north side of Eyahpaise Lake in the Glennie Lake Domain. Four zircon fractions yield an age of 1872±34 Ma. The age indicated has a relatively large uncertainty and is somewhat greater than other plutons dated in the Glennie Lake Domain (e.g. HUD-83-11, Deschambault Narrows Tonalite, 1850±4 Ma). Further work may lead to revision of the age reported here.

HUD 83-14 Late pluton that intrudes Eyahpaise Pluton: This sample is of biotite granodiorite from a small circular pluton that intrudes the larger Eyahpaise Pluton. The sample was collected from the shore of an unnamed lake northwest of Stevens Lake. Four zircon fractions yield an age of 1836±7 Ma.

HUD 84-104 Star Lake Pluton, La Ronge Domain: Four fractions of the abundant zircons yielded by this sample indicate an age of 1852±21 Ma, a result consistent with the age range of other plutons in the La Ronge Belt (see Table 1).

HUD 84-RL11: This sample of granite to quartz monzonite from the Wathaman Batholith was collected by Michael T. Meyer from an outcrop on Reilly Lake for his M.Sc. thesis research. His analysis of seven zircon fractions indicates an age of 1856±8 Ma, a result consistent with our earlier analysis of sample HUD 83-18 from the Wathaman Batholith (Table 1).

HUD 83-23 Metarhyolite from McLennan Lake, La Ronge Domain: This sample of metarhyolite containing prominent quartz phenocrysts was collected along Highway 102 adjacent to the northwest end of McLennan Lake. This sample has not yielded many zircons and it has been difficult to obtain a precise age. The data now at hand are based upon analysis of four small zircon fractions and indicate an age of 1879±66 Ma. The age is consistent with that obtained for all of the other volcanic rocks dated thus far, but the uncertainty is large. We note, however, that this sample is very similar to HUD83-24, a metarhyolite collected only a few kilometres away from the same domain. HUD83-24 yielded an age of 1877±8 Ma (see below and Table 1).

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Field and logistic support by the Saskatchewan Geological Survey with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Table 1 — Summary of U-Pb (Zircon) results

Sample No.: Unit	*N*	*P*	*Model*	*Age (+ 2σ)*	*L.I.*
HUD83-1: Metafelsite from Laroque Lake	5	<1	2	1876 ± 33	203
HUD83-3: Tonalitic gneiss, Davin Lake Complex	4	54	1	1863 ± 12	786
HUD83-5: Brindson Lake Pluton	4	30	1	1866 ± 12	0
HUD83-6: Carroll Lake Gneiss	4	1	2	1893 ± 35	560
HUD83-7: Palf Lake Metarhyolite	3	93	1	1881 ± 6	115
HUD83-8: Sahli Granite	(see text)			1900/2500	
HUD83-9: Hanson Lake Metarhyolite	4	90	1	1888 ± 12	460
HUD83-11: Deschambault Narrows Tonalite	4	96	1	1850 ± 4	74
HUD83-12: Wykes Lake Pluton (granodiorite)	4	<1	2	1844 ± 12	169
HUD83-13: Eyahpaise Pluton	4	6	2	1872 ± 34	394
HUD83-14: Late pluton; intrudes HUD83-13	4	17	2	1836 ± 7	97
HUD83-16: "Older Gneiss"; = Eyahpaise?	6	<1	2	1852 ± 12	432
HUD83-17: Tonalitic Gneiss, Davin Lake Complex					
Unprocessed zircons (Group 1 less M(2))	5	21	1	1887 ± 11	652
Air-abraded suite (Group 2)	4	1	2	1922 ± 23	734
Hand-picked coreless (M(-3)	1	—	1	1868 ± 9	700*
HUD83-18: Wathaman Batholith	6	<1	2	1852 ± 14	450
HUD83-19: Peter Lake Domain	1	—	—	2503 (Pb-Pb)	
HUD83-20: Macoun Lake Pluton	4	77	1	1849 ± 10	380
HUD83-23: McLennan Lake Metarhyolite A	4	0	2	1879 ± 66	670
HUD83-24: McLennan Lake Metarhyolite B	6	33	1	1877 ± 8	570
HUD84-29: Metarhyolite, Ennadai Gp., Hamill Lake	6	22	1	2683 ± 7	930
HUD84-104: Star Lake Pluton	4	<1	2	1852 ± 21	478
HUD84-133 Metarhyolite, Upper Waddy Lake	4	62	1	1884 ± 5	106
HUD84-301: Granodiorite, Tazin Lake	4	99	1	2595 ± 7	766
HUD84RL11: Wathaman Batholith, Reilly Lake	7	90	1	1856 ± 8	651

Notes: N = number of fractions, P = probability of fit (in percent); Model refers to models of Ludwig (1980, 1982) for models 1 and 2, and to Ludwig (1983) for model 4; Ages given in Ma, with uncertainties at 2 sigma. See text for further details.
*Assumed lower intercept.

HUD 84-133 Metarhyolite, Upper Waddy Lake, La Ronge Domain: This sample of quartz-phyric metarhyolite yielded abundant zircons with sharply euhedral form typical of volcanic rocks. Four fractions of these indicate an age of 1884±5 Ma, a result consistent with the ages of all rhyolite samples we have determined from the La Ronge Domain, the Glennie Lake Domain and the Hanson Lake Block (see Table 1).

HUD 83-19 Granite from the Peter Lake Domain: This sample was collected along Highway 105 west of Peter Lake. The sample did not yield many zircons. Analysis of the least magnetic fraction has yielded a $^{207}Pb/^{206}Pb$ age of 2503 Ma. Because the $^{207}Pb/^{206}Pb$ age should be considered a minimum age for this sample, it is clear that the rock in question is of Archean age. This result is consistent with the age of approximately 2510 Ma reported by Ray and Wanless (1980) for a dioritic tonalite from the Peter Lake Domain and also for the Johnson River granite, a domed inlier in the Wollaston Domain.

HUD 84-29 Metarhyolite from the Ennadai Group: This sample was collected by R. Macdonald in the NTS 64M sheet area near Hamill Lake close to the Northwest Territories border. The zircon yield is excellent; six fractions indicate an age of 2683±7 Ma, confirming the Archean age of this rock.

HUD 84-301, granodiorite from the north shore of Tazin Lake: This sample of granodiorite from the Nolan Block yielded an age of 2595±7 Ma based on the analysis of four zircon fractions.

Revised Results

HUD 83-1 Metafelsite from Laroque Lake, La Ronge Domain: In last year's report (Van Schmus and Bickford, 1984) we indicated that the age of this sample was 1870 to 1940 Ma. This broad age range was indicated because our original sample yielded very few zircons and the resulting analyses did not permit a more precise interpretation of the age. During the summer of 1984 a new sample was collected by R. Macdonald at the same locality. The zircon yield was significantly better and permitted analysis of five zircon fractions, including the originals. These data indicate an age of 1876±33 Ma, a result consistent with the ages we have found for all of the volcanic rocks studied from the La Ronge Domain, Glennie Lake Domain and Hanson Lake Block (Table 1).

HUD 83-17 Tonalitic gneiss from Davin Lake complex, Rottenstone Domain: The zircons from this sample are quite complex. Many of the separated zircons have clearly visible cores with relatively clear overgrowths. As indicated in Table 1, the original analysis of five zircon fractions indicated an age of 1887±11 Ma, but an additional zircon fraction does not plot with this array and is excluded. Because we could see the cores in zircons microscopically, we air-abraided a suite of four zircon fractions. This suite yielded an age of 1922±23 Ma, but this age is presumably strongly influenced by the inherited core material. Most recently, we have hand-picked a core-free zircon sample from the least-magnetic (and therefore most concordant) fraction. Analysis of this sample yields an age of 1868±9 Ma, assuming a lower

concordia intercept of 700 Ma. This age is more consistent with the ages of most of the plutons we have studied in the La Ronge Domain and is also consistent with our other sample from the Davin Lake tonalitic gneiss complex (HUD 83-3) which yielded an age of 1863±12 Ma. Our preliminary result from the core-free zircon fraction will have to be confirmed by analysis of core-free samples from other magnetic fractions.

HUD 83-24 Metarhyolite from McLennan Lake: This sample, collected along Highway 102 adjacent to McLennan Lake, is a metarhyolite with abundant quartz and feldspar phenocrysts. Our original analyses (Van Schmus and Bickford, 1984) indicated an age of 1930±26 Ma. Further processing, including air-abrasion and hand-picking, have given analyses of six fractions indicating an age of 1877±8 Ma. This result is not only more precise than the previously reported age but is also more consistent with the ages of other volcanic rocks studied.

Summary of Age Results

The ages obtained thus far indicate that igneous activity in the Trans-Hudson Orogen began with volcanism about 1875 to 1885 Ma ago. The volcanic rocks represented (Table 1) were collected from the La Ronge Domain (HUD83-1, -23, -24, HUD84-133), Glennie Lake Domain (HUD83-7) and Hanson Lake Block (HUD83-9); thus, it is likely that several volcanic centres were active at this time. Plutons, including our only dated samples of the Wathaman Batholith, were emplaced into the eruptive rocks between 1870 and 1850 Ma ago. The Carroll Lake Gneiss, a strongly deformed rock from the Glennie Lake Domain, yields an age of 1893±35 Ma; it could represent somewhat older material or could be a deformed early pluton.

The only indications of Archean rocks within the orogen itself come from the results for the Sahli Granite, a charnockitic rock exposed in a structural dome in the Hanson Lake Block. This unit yields a mixed population of zircons including clear, strongly euhedral forms and rounded dark corroded zircons. Analysis of these has indicated that the age lies between perhaps 1900 and 2500 Ma; a possible interpretation is that the rock is Archean basement material metamorphosed at high grade during the initiation of orogeny about 1900 Ma ago. Very preliminary results from the MacMillan Point granite, which is also exposed in a dome in the Hanson Lake Block, are similar.

As noted above, the preliminary age of our sample from the Peter Lake Domain, 2503 Ma, is consistent with published results (Ray and Wanless, 1980) and indicated that at least some of the rocks there are Archean. As discussed below, we made more extensive collections in the Peter Lake Domain during the 1985 field season. The Archean age obtained for the metarhyolite from the Ennadai Group in extreme northeastern Saskatchewan confirms earlier conclusions.

Sampling Program, Summer 1985

During the summer of 1985, Bickford spent ten days sampling with J.F. Lewry and K.D. Collerson, both of the University of Regina. The sampling program was aimed at initiating studies of the age and isotopic characteristics of rocks from the region west of the Needle Falls Shear Zone, including presumed Archean rocks west of the Virgin River Shear Zone, rocks of unknown age within the Mudjatik Domain, rocks intrusive into the Wollaston Group in the Wollaston Domain, and rocks from presumed Archean domal inliers in both the Wollaston and Peter Lake Domains. Bickford and Collerson took samples of the same rocks (see Collerson and Lewry, this volume).

A goal of our research during the next several years is to obtain isotopic data for the Sm-Nd and Rb-Sr systems as well as precise age data from U-Pb analysis of zircons. The zircon work is expected to continue at the University of Kansas, whereas Collerson is expected to begin study of the Sm-Nd and Rb-Sr systems in a new laboratory being built at the University of Regina. The zircon analyses will provide the primary chronology for the formation of the rocks being studied, whereas Collerson's isotopic measurements will provide constraints on the origin of the rocks and allow consideration of the generation and evolution of continental crust during this period.

Of particular interest are the following:

1) What is the age of the rocks of the Western Craton? Are these rocks as old as some of the material found in the Slave Craton to the north, or in the Wyoming Craton to the south? If so, ages in excess of 3.0 Ga could be expected.

2) What is the age of the Mudjatik Domain? Are these rocks mostly Archean, as has been considered , or are many rock bodies of Hudsonian age? Of particular interest will be the extent to which Hudsonian remobilization or 'overprinting' of Archean rocks can be detected.

3) In the Wollaston Domain we shall be interested in the age of supposed Archean rocks, now exposed within domal inliers, which are presumably basement to the Wollaston Group metasedimentary rocks. We shall also be interested in the extent to which these rocks may reveal deformation and metamorphism, either during early rifting events prior to the initiation of orogenic activity or during orogenic events.

4) Finally, we shall be interested in the age and origin of the enigmatic rocks of the Peter Lake Domain. Some of these rocks are already known to be Archean (see above). Is the Peter Lake Domain a fragment of older craton deformed during Hudsonian events? Could it be a microcontinent rafted in during Hudsonian collisional events? What is the origin and significance

of the abundant mafic and ultramafic rocks in the Peter Lake Domain?

The samples collected for these new investigations have been described by Collerson and Lewry (this volume).

Acknowledgements

All of our work has been done in collaboration with J.F. Lewry of the University of Regina and R. Macdonald of the Saskatchewan Geological Survey. Bickford and Van Schmus are supported by a grant (EAR 9313167) from the National Science Foundation of the United States Government. Field and logistical support for us and our students has been provided by the Saskatchewan Geological Survey. We are grateful for the financial support and for useful and stimulating exchanges with R. Macdonald, J.F. Lewry and K.D. Collerson.

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Project 8403

The Martin Group: Tazin Lake, Charlot Point and Jug Bay Areas

by P.K. Mazimhaka [1] and H.E. Hendry[1]

Mazimhaka, P.K. and Hendry, H.E. (1985): The Martin Group: Tazin Lake, Charlot Point andJug Bay areas; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Work on the sedimentology of the Martin Group was extended to outcrops of the group outside the Beaverlodge area during the summer of 1985. Areas covered include Tazin Lake, Charlot Point and Slate Island, and Jug Bay. This represents near complete coverage of known occurrences of the Martin Group (Fig. 1).

Detailed work included measurement of stratigraphic sections, studies of clast composition in conglomerates, and facies description. Other cover formations in the area were examined to establish their interrelationships and their relation to the Martin Group. A major objective of the work is to obtain sufficient data to enable us to compare and correlate all the scattered remnants of the group in the Greater Beaverlodge area and to evaluate the proposals of Langford (1981).

Exposures of the Jug Bay Formation along the Crackingstone Peninsula are generally poor and detailed stratigraphic sections could not be obtained. The Pebble Island Formation is exposed on three small islands off Gurchy Point and good exposures are very limited indeed. The Charlot Point Formation to the northeast is well exposed along the south shore of Charlot Point and along the lakeshore herein referred to as "Boulder Beach" (Fig. 2). Exposures on Camsell Peninsula, Slate Island and around Wellington and Waterloo Lakes were also examined. In the Tazin Lake area, problems of poor and limited exposures are compounded by numerous faults criss-crossing the area. A high water level this season made some good exposures inaccessible. The Martin Group rocks extend from Taz Bay in the east to the Northwest Bay. Exposures are limited to the shoreline and islands (Fig. 3).

Previous Work

Rocks belonging to the Martin Group were originally lumped together with other unmetamorphosed to weakly metamorphosed sedimentary sequences overlying the highly deformed and metamorphosed Tazin Group of the basement (Hale, 1953, 1954, 1955).

Koster (1968, 1970) used the name Martin Formation for rocks lithologically similar to Hale's Athabaska Series (Hale, 1953, 1954, 1955) in the Tazin Lake area. Scott (1978) subsequently subdivided the cover rocks into the Thluicho Group, Ellis Bay Formation, Martin Formation and Athabasca Series. Although the Martin Group overlies the Thluicho Group, the only contact observable between the groups is the unconformity on the west end of Slate Island. This is in contrast to the numerous exposures of the unconformity between the Martin Group and the Tazin Group.

The nomenclature and subdivision of the Martin Group rocks used in this and other reports (Mazimhaka and Hendry, 1984) follow closely that suggested by Langford (1981). The Charlot Point Formation includes "a boulder conglomerate facies that intertongues with a sandstone facies ... it unconformably overlies the Thluicho Group on Slate Island" and "is unconformably overlain by the Fair Point Formation of the Athabasca Group" (Langford, 1981). Similar rocks outcrop in two major structural zones between Lake Athabasca and Tazin Lake in the Thluicho Lake-Gulo Lake basin, and in the Wellington-Waterloo Lake basin (Scott, 1978). The Charlot Point Formation conglomerates and sandstones were derived from a predominantly sedimentary source area.

In the Tazin Lake area, interlayered arkose and shale previously mapped as Upper Athabasca (Hale, 1953, 1954) or as unit 15 and parts of unit 14 of the Martin Formation (Koster, 1968) are now considered as part of the Thluicho Group. The rocks cover a large part of David Island, as well as the South and Central "Windward Islands" of this report, and southeast of Olson Bay (Fig. 3). The northwestern extension of the Martin Group was examined only as far as the Barber Point area, but there are small scattered exposures farther north not reached this season.

Taz Bay Formation

The Taz Bay Formation and the Thluicho Group

The Taz Bay Formation (Langford, 1981) was mapped by Hale (1953, 1954) as part of a Proterozoic sequence of conglomerates and arkoses (Unit 7) along the south shore of Tazin Lake and on David Island. Koster (1968, 1970) mapped and described the northern extensions of the same rocks and assigned them to the 'Martin Formation'. In the Taz Bay area, units 11 and 12 of Koster (1970) were described as "conglomerate and granite wash" and "arkose, locally with layers of conglomerates" respectively. In the Zin Bay area, Koster (1968) described "conglomerate and granite wash" as unit 13, "arkose; locally layers of conglomerate, conglomeratic arkose" as unit 14, and "interlayered arkose and mudstone pseudo-conglomerate" as unit 15. As a result of field work in the 1985 season, rocks of unit 15 (Koster, 1968) have been assigned to the Thluicho Group. Langford (1981)

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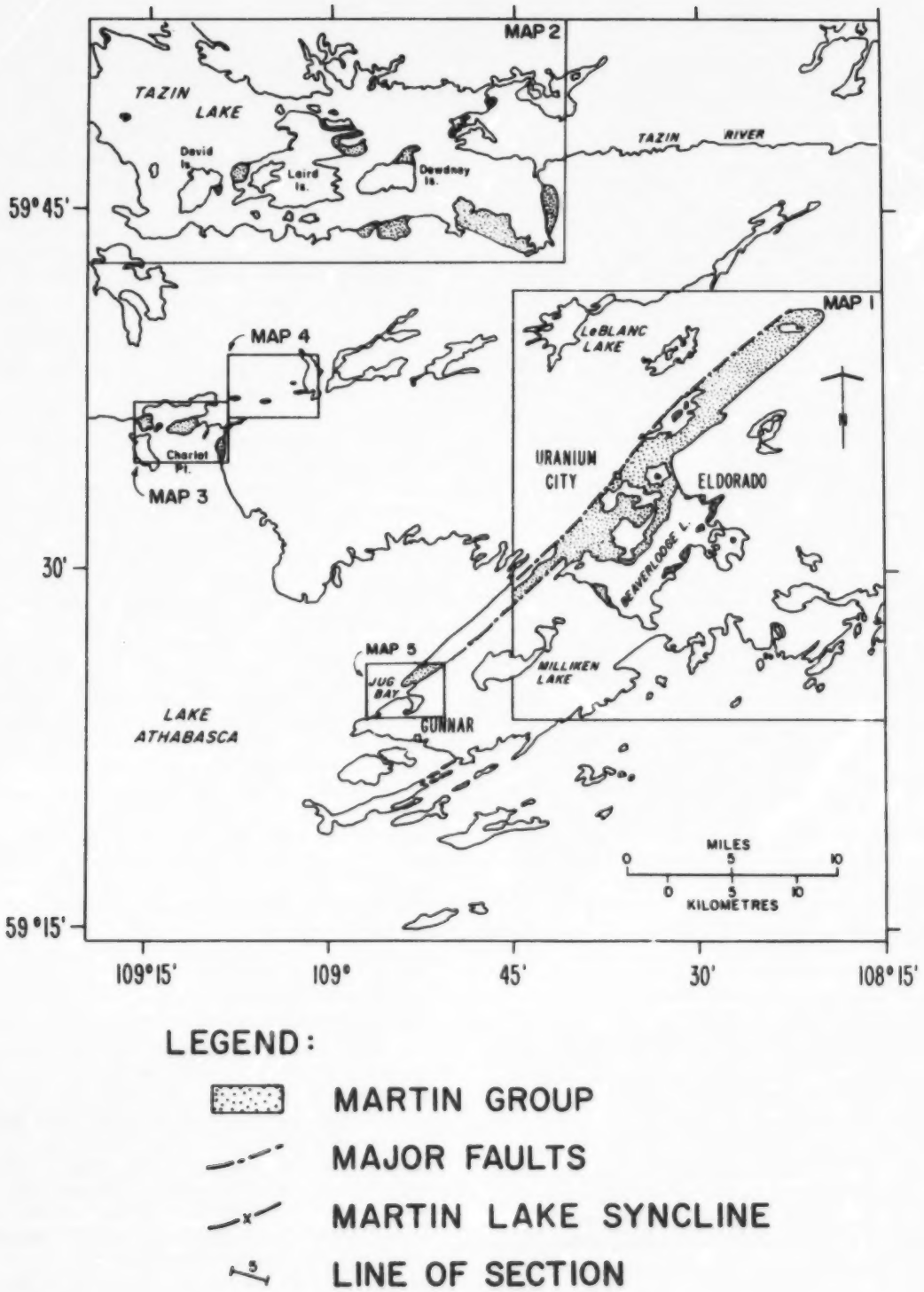
Project contracted to the University of Saskatchewan with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.



LEGEND:

- MARTIN GROUP
- MAJOR FAULTS
- MARTIN LAKE SYNCLINE
- LINE OF SECTION

Figure 1 - Location map of the Martin Group, Greater Beaverlodge area.

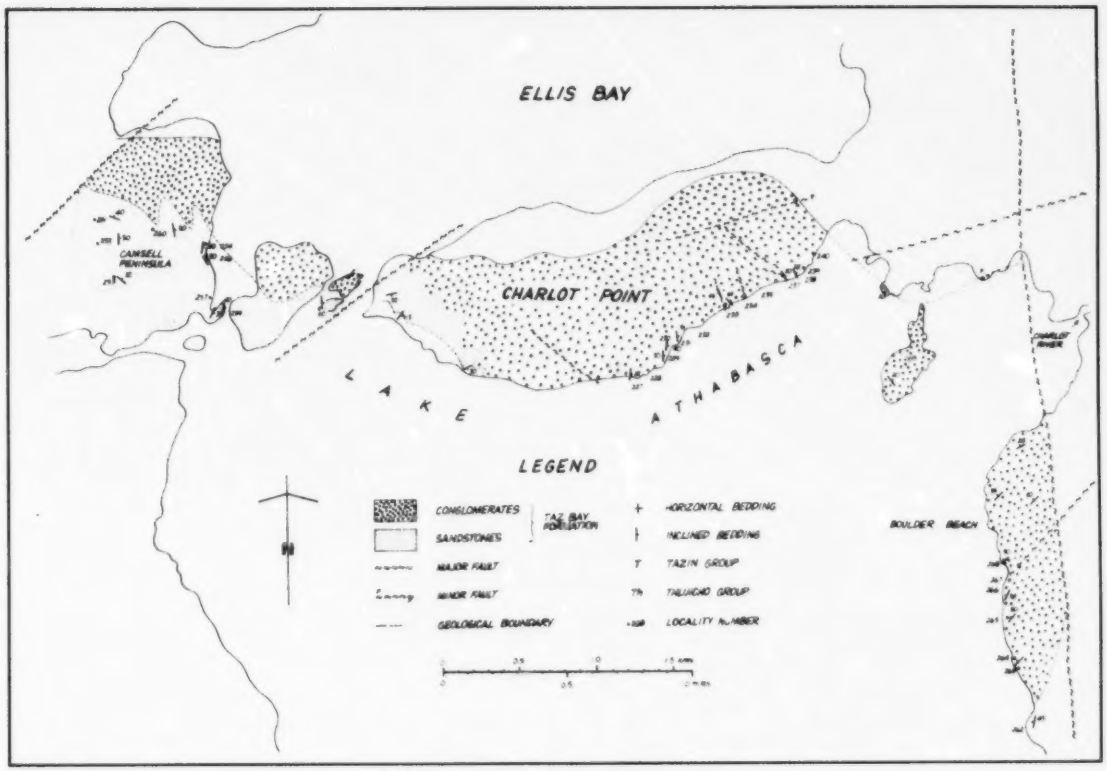


Figure 2 *- Outcrop and locality map of the Charlot Point Formation in the Charlot Point area. Geology after Scott (1978).*

suggested that Scott (1978) had mapped them as such on David Island, although Scott's mapping did not cover the area.

The relationship between the Thluichc and the Martin Groups is commonly obscured by fault zones and because of general lithological similarities it is difficult to distinguish them. In other areas, however, even where no contacts are seen, there is enough structural discordance and lithological differences to distinguish them. Thus, in the Tazin Lake area, Thluicho Group rocks are reddish sandstones interbedded with dark grey to black shales, intensely folded and very steeply dipping or overturned. On David Island, Thluicho rocks are separated from the Taz Bay Formation by north- to northwest-striking faults. At the south end of Olson Bay, Thluicho Group rocks comprise very well indurated thinly bedded sandstones and black shales, whereas to the north the shale beds are reduced to shaly partings in reddish-grey thinly bedded and graded sandstones. The overlying Taz Bay Formation consists of pinkish-red cross-bedded pebbly sandstones with reddish siltstone partings and conglomerate beds. Thluicho Group rocks dip from 60º to the northeast to vertical, and dips of the Taz Bay Formation rocks are between 10º and 35º to the northeast.

The Sub-Martin Unconformity in the Tazin Lake Area

The sub-Martin unconformity on basement gneisses and schists is exposed in several places on Laird Island and north of Barber Point, where it is highly irregular and unweathered. Although the surface appears to have developed on faulted or brecciated basement rocks, there is no evidence of regolith or weathered material on the unconformity. Fragments from basement rocks immediately underlying the unconformity may be traced upwards in the overlying conglomerates for several tens of centimetres.

On Laird Island, west of Laird Bay (locality 281, Fig 3), the unconformity is a fresh surface developed on granite gneisses. The surface slopes to the east at 20º, and on the next ridge (locality 282, Fig. 3) it slopes to the southeast. Conglomerates of the Taz Bay Formation immediately above the unconformity are polymictic and interbedded with sandstone lenses. Large rafts up to 110 cm long from the granite gneisses below occur several metres upwards into the conglomerate. To the west in Mitchell Bay, the unconformity surface is flat lying and developed on a fault zone (locality 310, Fig. 3). The basement consists of a

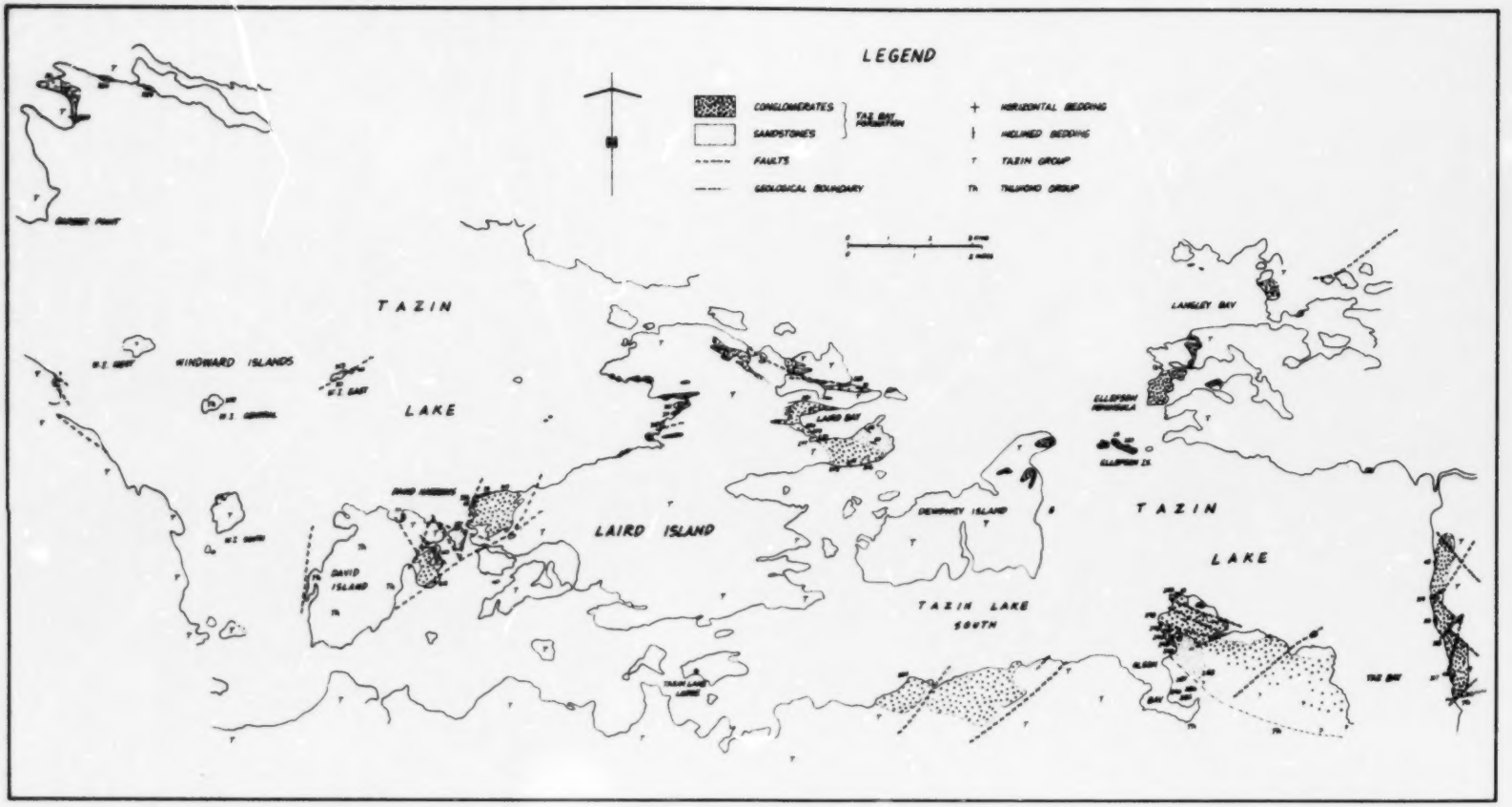


Figure 3 *- Outcrop and locality map of the Taz Bay Formation, Tazin Lake area. Geology after Koster (1968, 1979) and Hale (1953, 1954). "Tazin Group" in this figure refers to basement rocks.*

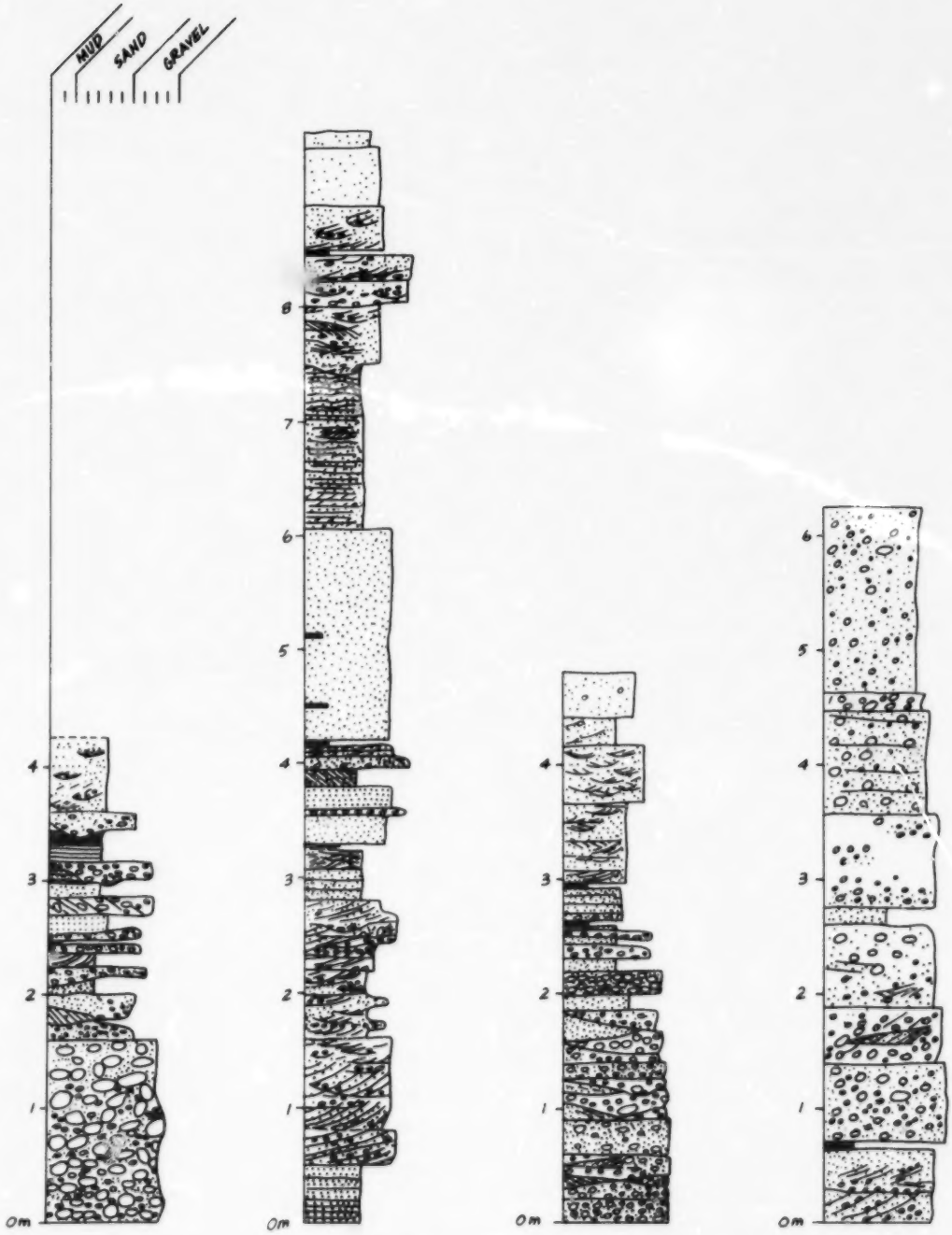


Figure 4 - *Stratigraphic sections in the Taz Bay Formation, Olson Bay (localities 288, 292, 293 and 294 on Fig. 3).*

suite of gneissic and foliated amphibolitic rocks intruded by calcite veins. Fragments of the basement grade into the lower few centimetres of the overlying conglomerate. The conglomerate is a clast-supported cobble-grade rock with up to 20 percent sand matrix. At the western end of Laird Island (David Narrows East, locality 329, Fig. 3), conglomerates of the Taz Bay Formation were deposited on a sharply defined surface, developed on a 2 m wide sheared and brecciated zone in interlayered augen gneisses and fine-grained granite. The conglomerates consist of small cobbles and are interbedded with massive brown siltstone with beds up to 30 cm thick.

North of Barber Point, the unconformity is exposed at

locality 324 (Fig. 3) where it is a steeply inclined, sharply defined surface developed on brecciated migmatitic rocks. The conglomerates above the unconformity are very coarse with clasts up to 140 cm in size, and are poorly sorted, polymictic and well rounded. The matrix is a poorly sorted aggregate of material ranging from mud to gravel.

Although these few exposures of the sub-Martin unconformity are instructive, they do not provide sufficient basis for the reconstruction of the pre-Martin relief. In the Tazin Lake area, many of the Martin Group rocks may lie under the lake. Faulting in the area makes it impossible to reconstruct either the unconformity surface or the sequence and facies relationship from small exposures so far apart.

The Taz Bay Formation is the only formation of the Martin Group exposed in the Tazin Lake area. The exposures are small and more than 40 km apart from the southeastern to the northwestern shores of the lake, and more than 10 km apart from the north to the southern shores. The Taz Bay Formation crops out on the eastern side of the lake between the Tazin River and the Taz Creek, as well as along Olson Bay and in the hills east of the bay. In the central area of the lake it is exposed around Ellefson Bay, on the northeastern tip of Dewdney Island, on the lake shore south of Dewdney Island and on Laird Island. To the west and northwest, exposures are found on David Island, East Windward Island and north of Barber Point (Fig. 3). The extent and quality of exposure vary from place to place, from faulted but long exposures in the Olson Bay area to small scattered faulted inliers in the Mitchell Bay area. Because of the lack of continuity of outcrops, no attempt has been made at this stage to compile stratigraphic sections typical of the formation.

Eastern Tazin Lake

Along the eastern shore of Tazin Lake, the Taz Bay Formation outcrops north of the Tazin River, between the Tazin River and the Taz Creek and on the islands in Taz Bay. It is bounded by faults to the east and south. To the south, conglomerates and interbedded sandstones of the Taz Bay Formation are faulted against Thluicho Group pebbly sandstones interbedded with maroon, dark brown and pale green shale and siltstone.

Conglomerates of the Taz Bay Formation are well sorted and bedding is well developed. Beds up to 1 m thick are common, and the maximum clast size is 340 mm. Though most clasts are well sorted and rounded, clasts with very sharp and delicate edges occur in the coarser members. Sandstone lenses, beds and open-work conglomerate beds and patches are common.

Olson Bay Area

Rocks of the Taz Bay Formation exposed on the hills between Olson and Tazin Bays are estimated to be 950 m thick. Short sections totalling 68 m were measured along the eastern shore of Olson Bay. The Taz Bay Formation rocks consist of very coarse bright pink sandstones. Pebbly bases, crossbeds and scouring are common features in the lower part. Up section, sandstones are subordinate to conglomerates; they are finer and commonly rippled, and thin siltstone beds occur.

Conglomerates are predominantly clast-supported with sand matrix, and cross-bedded with clast imbrication and erosional contracts. Sorting is poor both in the clasts and the matrix. This type of conglomerate occurs in association with deeply scoured and cross-bedded pebbly sandstones. Another type of clast-supported conglomerate is bimodally well sorted with no sand-grade material. Maximum particle size is between 100 and 150 mm. Conglomerates of this type are associated with interlayered pebble conglomerate and pebbly sandstone beds up to 100 cm thick (Fig. 4).

Matrix-supported conglomerates are uncommon but two such rock types are recognized in the area. One is polymictic and forms beds up to 30 cm thick with very coarse sand matrix. It is interbedded with cross-bedded conglomerate and sandstone beds up to 15 cm thick. The other has a very fine sand matrix and very little pebble- to granule-grade material; maximum clast size is over 200 mm and the beds are over 100 cm thick.

Thin (20 to 50 cm) upward-coarsening and upward-fining cycles are recognizable, but longer trends cannot be recognized because continuous measurable sections are too short. Clasts consist predominantly of garnet schists and granite gneisses. Palaeocurrents determined from cross-beds, imbrication and cluster bed forms indicate a predominantly southerly to southwesterly flow.

South Tazin Lake

Rocks of the Taz Bay Formation were mapped along the Tazin Lake shore south of Dewdney Island. The formation underlies the hills along the south shore and is cut off by a northeast-trending fault to the east and southeast. Good exposures occur along the shore although they were underwater during the 1985 field season. The accessible exposures were examined but only ten metres of section were measured (locality 284, Fig. 3).

In this area, the Taz Bay Formation consists of coarse, well-sorted, well-rounded and clast-supported conglomerates. Mean bed thickness is 50 cm and mean maximum particle size is between 200 and 300 mm. Sandstones are cross-bedded pebbly beds with deep cobble-filled scours. Sandstone beds are less than 30 cm thick and associated with open-work pebble conglomerates either as patches in the sandstone in distinct units at the base of the sandstone beds, or as small pebble- and granule-grade gravel scour-fills. Most of the conglomerate beds consist of a pebble-grade open-work conglomerate up to 10 cm from the base of the bed

overlain by a coarser and thicker middle portion of clast framework filled with unsorted sand and gravel matrix. The top is either a very coarse sand or is sorted. In pebble-grade beds the matrix is abundant, the open-work is partly filled with matrix and the top is commonly very coarse cross-bedded sandstone. In boulder-grade conglomerates, large clasts have a very fine sand- to silt-grade matrix around them and the rest of the matrix consists of coarse sandstone and patches of fine laminated sandstone.

Individual conglomerate beds coarsen upwards, except where the trend is reversed by introduced sand in the top. Longer upward-fining cycles are common, consisting of boulder conglomerates at the base and gravelly sandstone in the top. The upward-coarsening units are 40 to 80 cm thick and the upward-fining units are 140 to 220 cm thick. The sequences generally contain very little sand-grade material.

Palaeocurrent directions determined from clast imbrication are consistently to the south-southeast. Large clast long axis orientation measured at locality 284 is 175° azimuth.

Ellefson Islands

Good exposures of the Taz Bay Formation around Ellefson Bay occur on the north shore of the small islands at the entrance of the bay. Outcrops are narrow but clean. The formation here consists of very coarse and very well rounded conglomerates. Boulder conglomerates with clasts up to 113 cm are interbedded with small cobble- to pebble-grade conglomerates. Sorting is moderate to poor in the coarser conglomerates and the larger clasts are surrounded by small cobble-grade clasts in a very fine sand matrix. Some open-work conglomerate beds are present as thin beds. There is very little sand-grade material in the sequence.

Laird Island East

Conglomerates and sandstones of the Taz Bay Formation are exposed along the northeastern bay on Laird Island. On the southern side of the bay, a sequence of conglomerates and sandstones is exposed along the shore and the hills (localities 277, 278, 279, Fig. 3). At the western end of the bay and in the hills to the northwest (localities 280 and 281), the sub-Martin unconformity is well exposed. The conglomerates immediately overlying the unconformity are interbedded with thin sandstone beds. The conglomerates are polymictic, angular, poorly sorted and matrix supported in places. Basement rafts up to 12 cm in size occur in the basal part of the conglomerates near the unconformity.

Clast-supported well-sorted conglomerates with well-developed bedding, imbrication and laminated sandstone lenses are present up to several metres above the unconformity. Open-work conglomerate beds are interbedded with fine sand matrix-filled clast-supported conglomerates. The fine sand matrix is likely an infiltrate. Some conglomerates have laminated and graded sand matrix and these are commonly overlain by cross-bedded sandstones.

Farther south, at localities 277, 278 and 279, both clast-supported and matrix-supported conglomerates are interbedded with sandstones. The clast-supported conglomerates are commonly fully open or partially filled with sand matrix or calcite cement. The interbedded sandstones are well bedded, graded and commonly scoured. The matrix-supported conglomerates have poorly sorted angular clasts and a sand matrix.

Sand content in the sequence increases up-section, to the northeast, occurring in the form of matrix, lenses and beds. The sandstone lenses have eroded bases, low-angle cross-beds and are commonly graded. Farther up sequence and to the north of the bay, thinly bedded and ripple-laminated fine- to medium-grade sandstones are interbedded with siltstone.

Mitchell Bay

In the Mitchell Bay area, the Taz Bay Formation is exposed in small isolated outcrops along the shore (Fig. 3), where it overlies steeply dipping to near-vertical foliated basement gneisses. The gneisses are brecciated below the unconformity zone, and angular clasts derived from the basement can be traced for several tens of centimetres into the basal part of the conglomerates. The basal part of the conglomerate consists of very angular small cobble-grade clasts derived almost entirely from the basement immediately below. The conglomerate matrix consists of silt- and granule-grade gravel.

A section measured across the entire outcrop at locality 310 (Fig. 3), consists of 150 cm of very angular, crudely bedded and poorly sorted conglomerates with a poorly sorted to subrounded clast-supported conglomerates, interbedded with sandstone lenses thinning out to the south. The sandstones are cross-bedded, trough cross-bedded and massive. The maximum thickness of the sandstone beds is 50 cm.

Up-section (locality 311), the conglomerates are generally finer grained, and include numerous open-work conglomerates either as beds or patches (Fig. 5). Open-work conglomerate patches and beds are well-sorted. Upward-coarsening and upward-fining units are very common, although in the 12.5 m section there appear to be two upward-coarsening cycles 5 to 6 m thick. The conglomerates are entirely clast-supported, and comprise three common types: a) clast-supported and poorly-sorted with very coarse and unsorted matrix; b) clast-supported with very fine sand matrix and c) clast-supported conglomerates with open pores, calcite cement or sand matrix. Matrix makes up to one third of the rock in places. The clasts are predominantly foliated or granoblastic gneisses.

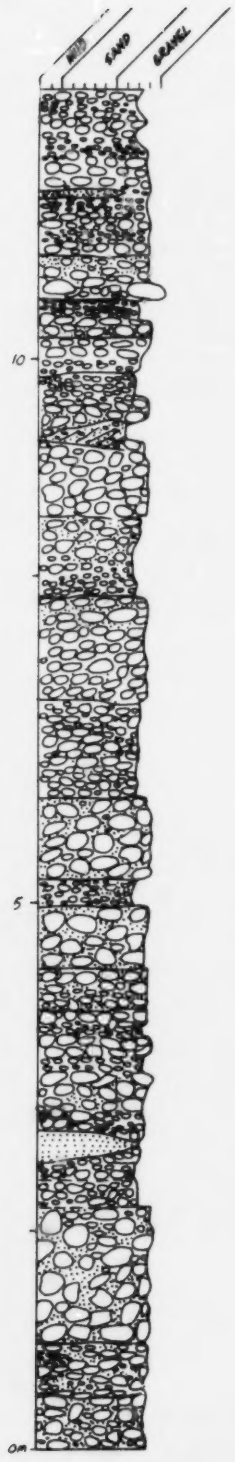


Figure 5 - *Stratigraphic sections in the Taz Bay Formation, Mitchell Bay (locality 311 on Fig. 3).*

Laird Island West and David Island

Rocks of the Taz Bay Formation are exposed as folded and faulted blocks on the western tip of Laird Island, on the small island between Laird Island and David Island, and on the eastern side of David Island. The sub-Martin unconformity is a clean surface commonly developed on faulted-brecciated basement gneisses and granitic rocks. On David Island the formation is faulted against the Thluicho Group to the west.

The sequence consists of conglomerates interbedded with sandstones and siltstones. Along the western end of Laird Island, the sequence is folded into a series of synclines and anticlines. The small island in the gap between Laird and David Islands is a faulted block consisting of conglomerates and basement on the east side and sandstones on the top and west of the island. The sequence of conglomerates, conglomerates interbedded with sandstone and siltstone is repeated on David Island.

The lowermost conglomerates are clast-supported cobble-grade with fine sand matrix, and are interbedded with massive siltstone a short distance above the unconformity. Up-section the conglomerate is interbedded with pebbly sandstone and siltstone. Mudcracks and wave ripples are common in the interbedded siltstone and sandstone. On slip surfaces along bedding planes in the siltstones there are platy minerals, probably sericite, and the rocks are commonly green.

'Windward Islands'

This unofficial name refers to four islands in the western part of Tazin Lake. Koster (1968) mapped rocks of the Taz Bay Formation, namely units 14 and 15, on all of them. The southern, central and eastern islands were visited during the 1985 field season. Rocks of the Taz Bay Formation present on the eastern island are red and purple cross-bedded sandstones with abundant intraformational conglomerates. Cross-bed sets are 5 to 10 cm thick and ripple lamination is common. On the other two islands, the sandstones and siltstones likely belong to the Thluicho Group.

Barber Point Area

Barber Point is at the northeastern entrance to Northwest Bay (Fig. 3). Rocks of the Taz Bay Formation crop out north of the point. Conglomerates in this section are poorly sorted and matrix-supported, and the matrix is a very coarse sand to granule-grade gravel. This type is commonly interbedded with wedge-shaped very coarse sandstone bodies. Clast-supported conglomerates with a moderately sorted coarse portion and an unsorted pebble- to granule-grade portion are present but not common. A thick succession of sandstones and siltstones exposed in a cliff at the mouth of the bay west of Zin Bay (locality 323) consists of flat-lying and thick-bedded

sandstones with thin siltstone intercalations. The sandstone beds are 80 to 125 cm thick. Cross-bedding, wavy lamination, platy minerals on bedding planes and mud chips are common. Cross-bed sets are commonly less than 10 cm thick in co-sets of up to 60 cm.

The sub-Martin unconformity in this area, exposed at locality 325 (Fig. 3), is a steeply dipping surface, sharply defined and developed on migmatites and amphibolitic gneisses of the Tazin Group. Overlying the unconformity are very coarse unsorted polymictic conglomerates, with clasts up to 148 cm in size floating in an unsorted mixture of gravel-, sand- and mud-grade grains.

Charlot Point Formation

The Charlot Point Formation is exposed on the northern shore of Lake Athabasca and as small inliers inland around Waterloo, Wellington and Gulo Lakes. The formation consists of sandstones and conglomerates overlying rocks of the basement and the Thluicho Group. The base of the sequence is exposed only on Slate Island where it forms a sharp angular unconformity with the Thluicho Group.

During the 1985 field season, detailed stratigraphic sections were measured on the southern side of Charlot Point and along Boulder Beach south of the Charlot River mouth. Exposures in these two areas are good. Exposures on Camsell Peninsula and on the small islands at the entrance to Ellis Bay show a similar sequence. Two small exposures of coarse conglomerate on Slate Island overlie intensely folded and sheared Thluicho argillites. Other exposures in the area are small and commonly intensely sheared.

Charlot Point

The Charlot Point Formation is well exposed along the south coast of Charlot Point. Beds consistently dip to the east and northeast, and appear to form a limb of a northerly-plunging syncline. Two major northeast-striking faults likely displace Charlot Point Formation rocks along Ellis Bay and the south side of Charlot Point. Several north to northwest-striking faults were mapped along Charlot Point (Fig. 2).

The section at Charlot Point consists of trough cross-bedded sandstones at the base overlain by conglomerates. Numerous outcrops, although interrupted by stretches of beach, afford a fairly good view of the succession. The sequence here is approximately 1400 m thick and sections totalling 550 m were measured in detail (Fig. 6).

The trough cross-bedded sandstones at the base of the sequence are coarse and contain pebbles either along bases of sets or scattered along the foresets. Sets of cross-bedding are 10 to 50 cm thick and commonly 50 to 100 cm wide. Up-section, the trough cross-bedded

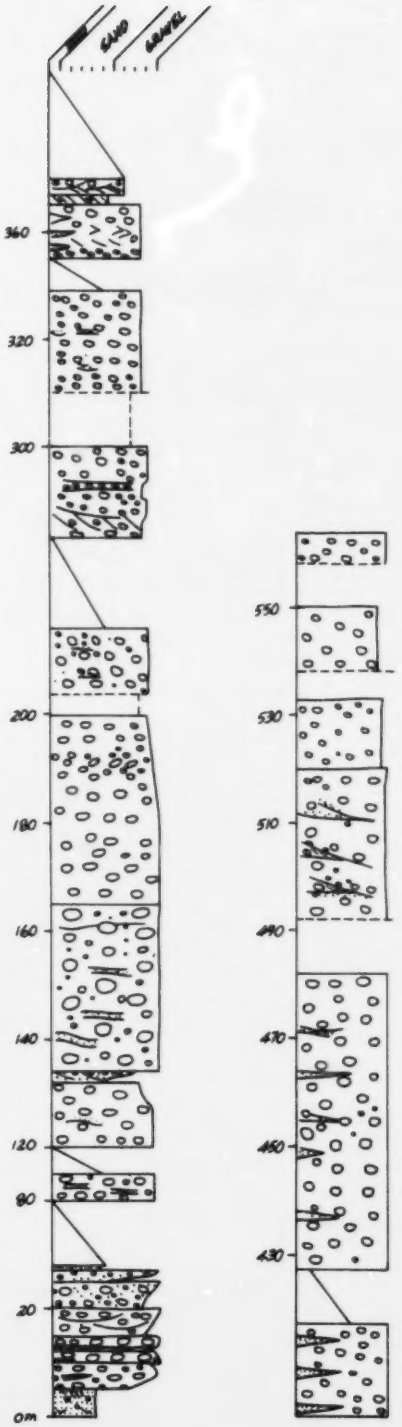


***Figure 6** - Stratigraphic section in Charlot Point Formation, Charlot Point (localities 226 to 242 on Fig. 2).*

sandstones are interbedded with horizontally bedded, planar cross-bedded and poorly stratified sandstones and conglomerates. At the base of the section, sandstones fill channel-like depressions with long axes parallel to the trough axes of cross-bedding. The sandstones pass laterally into conglomerates to the northeast.

Up-section, sandstones are overlain by and interfinger with crudely stratified clast-supported conglomerates. These conglomerates have horizontal to low-angle cross-beds which occur in lens-shaped stacks resembling shallow scours or scour-fill cross-bedding. Clast size is pebble- to cobble-grade. Boulders are few but well distributed. Boulders occur also in small pebble-grade and sand-grade beds and are commonly arranged in clusters. Low-angle cross-stratification passes laterally into cross-bedding. The contacts between sand lenses and beds and conglomerates are erosional or gradational.

In the upper part of the section, massive poorly sorted and clast-supported conglomerates occur with patches rich in sand but with no well-developed sand strata. The conglomerates contain pebbles to small cobbles (maximum pebble size 100 mm) and also a few boulders.

Conglomerates and sandstones in this sequence are poorly sorted. Sand drapes are common on top of conglomerate layers. Open-work conglomerates are rare but commonly have coarsely crystalline calcite cement. Clast imbrication and boulder clusters are common, and palaeocurrent directions indicated by these are towards the south and southeast. Similar directions were obtained from trough cross-beds in the sandstones lower in the sequence.

Conglomerate clasts in the Charlot Point Formation are almost entirely derived from a sedimentary source, as they are mainly sandstones, siltstones and conglomerates. The sandstones and siltstones have green-grey colour-banding due to chloritization. The argillites are dark grey, green and dark brown, and resemble Scott's (1978) "Meta-arkoses and Argillites" (units 5 and 6) of the Thluicho Group. The conglomerate clasts contain igneous and metamorphic clasts, particularly in the lower part of the section. A few metamorphic and igneous clasts observed in the sequence may have been derived from breakdown of conglomerates during transport.

Camsell Peninsula and Islands

Rocks of the Charlot Point Formation are exposed on Camsell Peninsula and on the small islands at the entrance to Ellis Bay. The sequence is similar to that on Charlot Point and forms part of the western limb of the main syncline. Although the formation seems to overlie rocks of the Thluicho Group to the north, no unconformity has been seen and the contact is marked by a very steep cliff which may indicate a fault zone.

Cross-bedded and trough cross-bedded sandstones, interbedded with thin conglomerate beds, are exposed on the southern half of the peninsula and the islands. The sandstones are coarse to very coarse grained. Sandstone beds are thin and interbedded conglomerates are well sorted and matrix supported. Individual conglomerate beds are normally graded and erosive. Pebbles and cobbles are commonly present in the foresets of the trough cross-beds. Intraformational mudstone clasts occur less commonly.

Clasts in the sandstone and interbedded conglomerates are markedly different from those in the upper part of the sequence, comprising mainly rusty brown sandstones with a cream or orange weathering rim possibly indicative of weathering of a ferruginous sandstone in the source area. A few conglomerate, igneous and metamorphic clasts are present.

To the north and northwest there is a lateral facies change from sandstone to conglomerate. Conglomerates interlayered with sandstones are cross-bedded. Up-section and to the north and northwest, however, the conglomerate is massive to crudely bedded.

Measurements of trough axis orientations in sandstones indicate current direction to the south and southeast.

Boulder Beach Area

The section exposed along the shore south of the Charlot River mouth is approximately 700 m thick and consists mainly of conglomerates with minor interbedded sandstones. This sequence is faulted against basement pelitic schists. Beds dip to the northwest and likely constitute the eastern limb of the syncline referred to in the Charlot Point section (Fig. 2).

Conglomerates in this section occur in four distinct facies:

1) Crudely stratified pebble- to cobble-grade clast-supported conglomerates with well-rounded clasts and very coarse sand matrix.

2) Well-stratified upward-fining cobble-grade conglomerates, interbedded with horizontally laminated sandstone. Upward-coarsening cycles consisting of medium-grade sandstone, pebble conglomerate, very coarse sandstone and cobble conglomerate are common.

3) Cross-stratified upward-coarsening conglomerates with sandstone lenses or horizontally-laminated sandstone.

4) Flood cycles characterized by alternating conglomerate and sandstone cross-beds up to 30 cm thick. Sandstones make tabular cross-beds which are scoured and wave rippled. Drapes and intraformational mudstone clasts are common. The matrix in the conglomerates is very coarse sand.

Open-work conglomerate occurs near the top of the sequence. In one outcrop the pores are partially filled with calcite. On the island opposite the Charlot River mouth, the calcite in some of the conglomerates appears to be in the form of veins cutting the poorly sorted sand matrix in the clast-supported conglomerates.

Other Occurrences of the Charlot Point Formation

The stratigraphic relationship between the Charlot Point Formation and the Thluicho Group is clearly demonstrated on Slate Island west of Camsell Peninsula, as the unconformity is well exposed on the west side of the island. The outcrops consist of several faulted blocks, two of which consist of intensely folded and sheared sandstone and siltstone of the Thluicho Group overlain by coarse, relatively undeformed conglomerates of the Charlot Point Formation. The unconformity surface slopes 30° to the north. Conglomerate clasts in the exposed basal part of the Charlot Point Formation are derived from and include large angular blocks of the Thluicho Group.

Other outcrops of the Charlot Point Formation in the Waterloo-Wellington Lake area (Fig. 7) occur along faults and are mostly deformed and sheared purple sandstones, pebbly red sandstones and siltstones.

Jug Bay Area

Rocks of the Martin Group crop out along the Crackingstone Peninsula between Lorado Mill and Gruchy Point, on islands in Jug Bay and on the Pebble Islands. There is a small exposure along the Jug Bay Fault east of Pebble Islands (Fig. 8). The main outcrop occurs between the Black Bay and Jug Bay Faults.

Fraser (1954) divided the cover rocks in this area into conglomerates, sandstones and arkoses. Sandstones exposed on Grouse Island belong to the Athabasca Group and those around Jug Bay area to the Martin Group. Langford (1981) divided the Martin Group rocks in the area into the Jug Bay Formation, which crops out along the peninsula and on the small islands in the bay, and the Pebble Island Formation cropping out on the Pebble Islands. The Jug Bay Formation consists of hard silicified reddish-brown and dark greenish-grey, fine-grained sandstone. The Pebble Island Formation consists of massive conglomerate and purplish-grey, well-bedded, coarse-grained arkosic sandstone (Langford, 1981).

Jug Bay Formation

The Jug Bay Formation overlies basement granitic rocks on an unconformable surface that slopes steeply to the

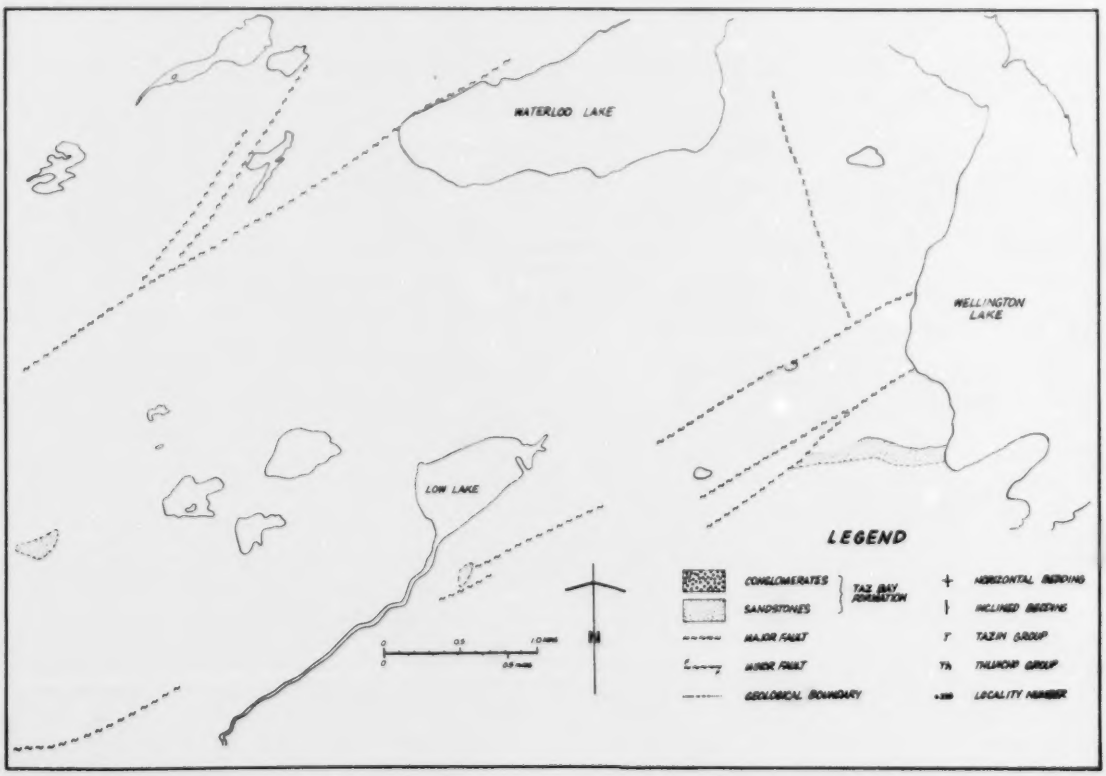


***Figure 7** - Outcrop and locality map of the Charlot Point Formation in the Waterloo-Wellington Lakes area. Geology after Scott (1978).*

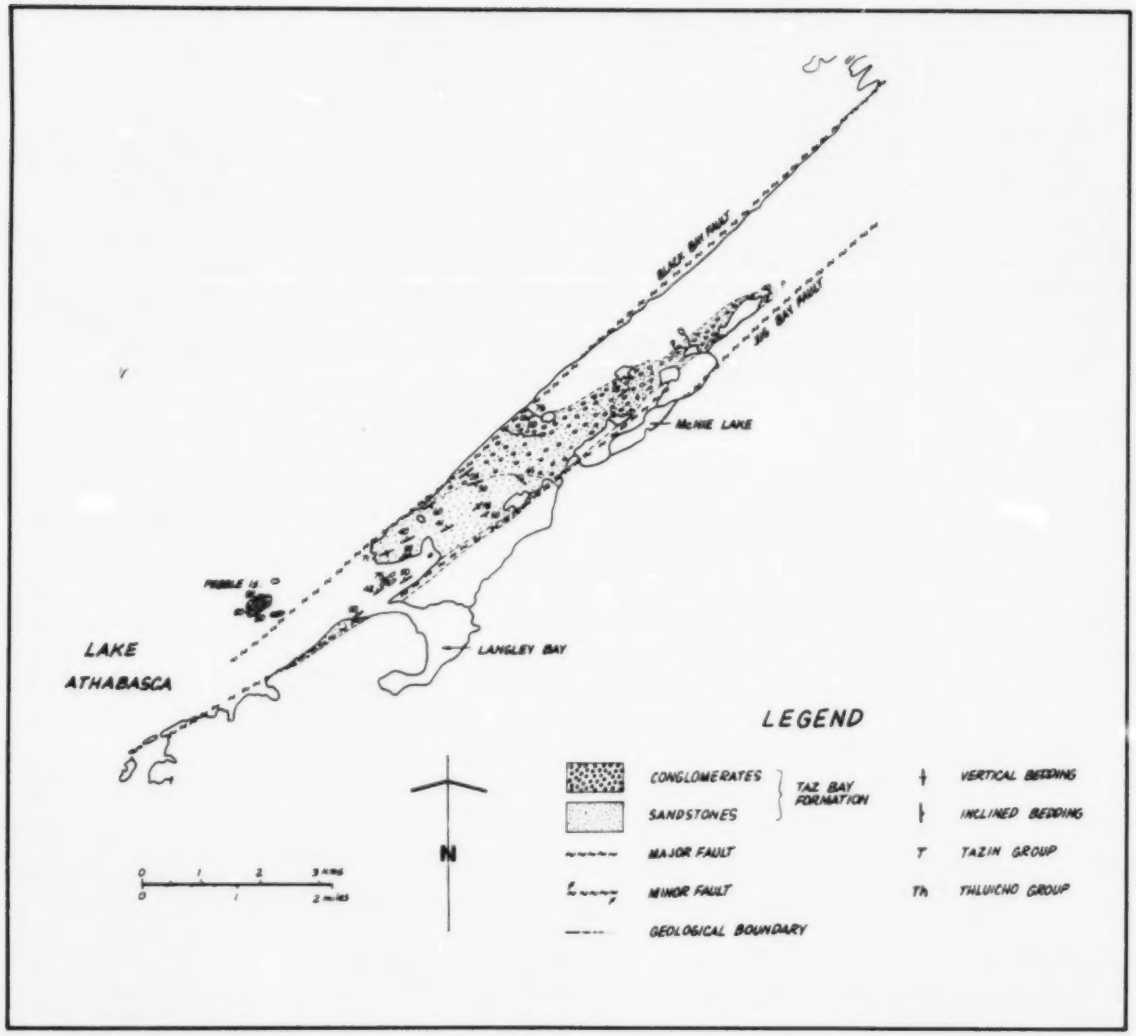


***Figure 8** - Outcrop and locality map of the Jug Bay and Pebble Island Formations in the Jug Bay area. Geology after Fraser (1954).*

southeast (locality 76, Fig. 8). The basement rocks are intensely sheared and brecciated, and the conglomerate at the base of the sequence consists of angular clasts derived from sheared basement. The matrix is very coarse sand- and granule-grade gravel with a similar composition to that of the clasts. The conglomerate is overlain by a medium-bedded siltstone, which is in turn overlain by pebble conglomerates interbedded with and grading into sandstones. The conglomerates are not well exposed but good exposures of the sandstones occur on the small islands in Jug Bay and north of the bay. The sandstones are well-indurated and grey, weathering red and brown. Grain size varies from fine to very coarse and pebbles are common at the base of the coarser beds. A few granule-grade beds are present but they are not very common. Sedimentary structures include planar cross-bedding, trough cross-bedding, wave ripples, horizontal lamination and scouring. Some syndepositional structures such as convoluted lamination and breccia are present. Bed thickness in the sandstones is highly variable but commonly between 10 and 80 cm. Clasts in the sandstones are granite, quartz and some green shale.

Rocks of the Jug Bay Formation have suffered moderate deformation. Besides the two major faults flanking the outcrop, several east-west faults cut across the formation, and numerous minor faults occur with displacements of up to 100 cm in beds and faulted pebbles. The Jug Bay Formation outcrop lies in a graben structure in the form of a tightly folded syncline. North of Jug Bay, sandstones with cleaved thin green shaly partings are tightly folded on northerly-plunging minor folds which are overturned to the west.

Pebble Island Formation

Conglomerates and sandstones of the Pebble Island Formation crop out on three islands southwest of Gruchy Point and west of the Black Bay Fault where they occur in a steeply dipping homoclinal structure (055/80 NW) bounded by the Black Bay Fault on the southeastern side. The estimated thickness of the outcrops beneath Lake Athabasca between the islands is 600 m.

The lower part of the sequence exposed on the small southernmost island consists of clay- and matrix-supported conglomerates. The conglomerates are poorly sorted but clasts are well rounded. There is no bedding but there is preferred orientation of large clasts in places. Maximum clast size in the lower part is 110 mm, increasing up-section to 175 mm. Outsized purple sandstone clasts are very common. The matrix, which forms up to 40 percent of the outcrop in some areas, is poorly sorted and consists of mud- and granule-grade material of the same composition as the clasts.

The source for the lower part of the sequence consists of metamorphic, igneous and sedimentary rocks. In the lower part, 50 percent of the clasts are white quartz, 30 percent are sedimentary rocks and 20 percent are metamorphic and igneous rocks. Several metres up-section, 56 percent of the clasts are sedimentary rocks, 28 percent are white quartz and 14 percent are metamorphic and igneous rocks. Sedimentary rocks include purple sandstone and reddish brown mudstone. The matrix component increases up-section from 30 to 40 percent.

On the other islands, the sequence is dominated by sandstone with a few conglomerate interbeds, particularly in the central area of the middle island. Two types of conglomerate are present: a coarse, very thick-bedded and clast-supported conglomerate with clasts up to 120 mm and a small cobble, thick-bedded and matrix-supported conglomerate with clasts up to 65 mm. The former contains outsized mudstone clasts and the latter is graded and cross-bedded.

Grain size in the sandstones is very variable. Pebbles are commonly present at the bases of coarse beds and in cross-bedded units. Common sedimentary structures are horizontal lamination in the fine- to medium-grade beds, cross-bedding, trough cross-bedding and ripple lamination.

Summary and Conclusions

1) During the summer of 1985, work on the Martin Group was extended to the Tazin Lake, Charlot Point and Jug Bay areas. Four formations of the Martin Group were examined: the Taz Bay Formation, the Charlot Point Formation, the Jug Bay Formation and the Pebble Island Formation.

2) All four formations consist of conglomerate and sandstone sequences and minor mud-grade rocks. In all four, basin development appears to have been controlled by active faults and the rocks were deposited in alluvial fans and braided streams.

3) Clast composition in the Taz Bay and Jug Bay Formations indicates metamorphic source rocks. In most cases clasts are similar to those of the basement rocks immediately below and around the formations. The Pebble Island Formation is derived from sedimentary, metamorphic and igneous rocks. The source for the sedimentary clasts may have been the Beaverlodge Formation to the north. Conglomerate clasts of the Charlot Point Formation are almost entirely derived from a sedimentary source, and most are identifiable as Thluicho Group.

4) The Taz Bay and Jug Bay Formations have similar characteristics to the Beaverlodge Formation with respect to relationship to the unconformity, basin development and depositional environments, and may be correlative. The relationship of the Charlot Point and Pebble Island Formations to the rest of the Martin Group is not yet clear. An erosional period between the lower Martin Group and the Gillies Channel has not been unequivocally established. Correlation between Gillies Channel and Charlot Point on one hand, and between Charlot Point and Pebble Island on the other, has not been proved.

Acknowledgements

The Martin Group Sedimentology Project receives logistic and financial support from Saskatchewan Energy and Mines and a University of Saskatchewan Scholarship. Financial Support was also received through the Canada-Saskatchewan Opportunities '85 Program. The Saskatchewan Research Council helped with field transportation.

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Quaternary Geology as a Guide to Mineral Exploration in the Southeastern Shield

by Bryan T. Schreiner[1]

Schreiner, B.T. (1985): Quaternary geology as a guide to mineral exploration in the southeastern Shield; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The Saskatchewan Research Council has recently entered into a joint venture agreement with Saskatchewan Energy and Mines to undertake a project entitled "Quaternary Geology as a Guide to Mineral Exploration in the Southeastern Shield". The objective of the work is to review what is known concerning Quaternary geology in this area and its application to drift prospecting for minerals, particularly gold. Any gaps in knowledge will be identified and investigations will be suggested to fill these gaps in information.

The area to be covered by this investigation will be the Central Metavolcanic Belt of the La Ronge Domain and the region to the southeast, extending eastward to the Manitoba border and southward to the edge of the Shield (Fig. 1).

The report is expected to include a review of existing information on the Quaternary geology and geochemistry. The common materials, particularly the till deposits, will be described using lithological parameters. Geochemical characterization of the tills will provide background levels and regional trends. Typical soil profiles will be provided for various sites with different materials and topographic aspects. Typical sections from exposures or drillholes will be presented to establish the stratigraphy of the drift deposits.

Generalized maps will be used to delineate the areal distribution of the surface materials, as well as to indicate the assumed thickness and topographic expression of the deposits.

A listing of explained and unexplained drift prospecting anomalies such as boulder trains and till dispersal fans will be included in the report. An attempt will be made to relate the distribution of gold in the Quaternary deposits to gold deposits in the belt.

The report will include a review and discussion of the problems of interpretation experienced by explorationists attempting to use Quaternary deposits for mineral exploration in the gold belt. In addition, recommendations will be made for future investigations to improve the effectiveness of drift prospecting in this area of gold potential.

The final report is scheduled for completion by March 31, 1986 and will be published or open filed jointly by the Saskatchewan Research Council and Saskatchewan Energy and Mines.

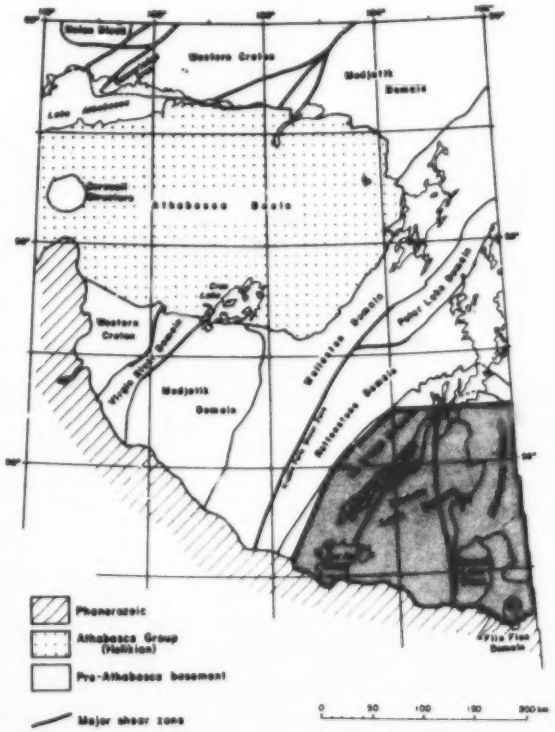

***Figure 1** - Location of the study area.*

[1]Resources Sector, Saskatchewan Research Council, Saskatoon. Project contracted to the Saskatchewan Research Council with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Project 8505

Mineralized Core Collection

by A. J. Gracie

Gracie, A.J. (1984): Mineralized core collection; *in* Summary of Investigations 1984, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The Mineralized Core Collection was described in the previous Summary of Investigations (Gracie, 1984). Additions to the collection, totalling some 2700 m, are described in Table 1.

An index to the collection, intended to facilitate its use by industry, was released on open file in February (Gracie and Gray, 1985). This file identifies the location of all the drill holes by latitude and longitude and on 1:250,000 scale maps, and gives full particulars of each hole (company, mineral disposition, exploration commodity, year, hole number, core size, hole bearing and inclination, length of sample core, reference to other available exploration data and storage location).

References

Gracie, A.J. (1984): Mineralized core collection; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p127-128.

Gracie, A.J. and Gray, L.J. (1985): Index to La Ronge Core Collection; Sask. Energy Mines, Open File Rep. 85-3, 145p.

Table 1 - Core Acquisitions, September 1, 1984 to August 31, 1985

Company or Joint Venture Operator/Commodity	*NTS Area*	*Number of Holes*	*Core Size*	*Property/Deposit (bit size)*	*Meterage (m)*
Benz Gold Resources Ltd./Ni-Cu	73P-6-SE	2 (partial)	Axt	ML 5196/Nemeiben Lake	35
Giant Yellowknife Mines Ltd./Au	64D-4-NW	5	BQ	ML 5337/Twin Zone	736
Golden Rule Resources Ltd./Au	64D-4-NW	9	BQ	ML 5332/'Weedy' Lake	720
Mahogany Minerals Resources Inc./U	74A-1-SW	1	NQ	Jolu claims/Mallard Lake, Rod zone	20
Minacto Ltd./U	74H-5-SE	4 (upper or sandstone sections missing)	NQ	ML 5228/Martin Lake	371
Saskatchewan Mining Development Corp./U	64L-5-SW	2	NQ	CBS 4728/Dawn Lake 11A and 11B Zones	354
Saskatchewan Mining Development Corp./U	74F-11-NE	1 (1 box missing)	Axt	CBS 8808/Derkson Lake	59
Uranerz Exploration and Mining Ltd./U	74H-6-SW	5 (upper or sandstone sections missing)	NQ	ML 5266/Mam Lake Zone	435

Activity funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Gold Deposits of the Flin Flon - Amisk Lake Area

by J.G. Pearson and A.G. Galley[1]

Pearson, J.G. and Galley, A.G. (1985): Gold deposits of the Flin Flon - Amisk Lake area; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The purpose of this report is to examine the evolution of gold deposits in the Flin Flon - Amisk Lake area.

General Geology

The Flin Flon belt comprises an assemblage of Aphebian submarine volcanic and associated sedimentary rocks, the Amisk Group, and an overlying group of immature, coarse, terrestrial sediments, the Missi Group (Fig. 1). The belt is in gradational contact to the north with the Kisseynew metasedimentary terrain and to the south is unconformably overlain by Ordovician limestone. It extends from the Wekusko Lake area of Manitoba to the Sturgeon Weir River in Saskatchewan.

Stauffer and Mukerjee (1971) recognized three main phases of Hudsonian deformation within the Missi Group. In addition, two generations of faulting have been recorded (Byers and Dahlstrom, 1954; Byers et al., 1965): an early generation coeval with the second phase deformation (P_2) and a later generation associated with the third deformation (P_3).

Four ages of igneous bodies intrude the supracrustals (Stauffer, 1974; MacQuarrie, pers. comm.). The oldest intrusions are subvolcanic granitic plutons (Cliff Lake pluton, Boot Lake pluton?). Gabbros followed by two ages of granites, the latest of which includes the Reynard, Annabel, Neagle and Phantom Lake plutons, were emplaced subsequently. Recent studies indicate that the Boot Lake pluton may also be a late intrusion.

Amisk volcanism occurred at 1.88 to 1.89 Ga with the last intrusive events occurring at 1.82 Ga (MacQuarrie, unpubl. data; Stauffer, 1985).

Douglas Lake - Phantom Lake Area

Stratigraphy

The stratigraphy throughout this area can be broadly correlated. In general, the base of the sequence comprises massive and pillowed basalts and associated fragmental rocks. These are overlain by rhyolite flows and pyroclastic rocks, graphitic argillite and a thick sequence of bedded, waterlain tuffs (Fig. 2).

The volcanic rocks are intruded by several bodies of gabbro and diorite, the Boot Lake and Reynard Lake granite plutons and the Phantom Lake porphyritic granite.

Gold Mineralization

There are two generations of gold mineralization respectively predating and postdating emplacement of the Phantom Lake pluton.

The earlier generation is manifested by occurrences (Newcor mine, Cor, Unity, Bomber Lake) in the lower basalt unit east of Douglas Lake (Fig. 2). Narrow (1 m wide) quartz-sulphide veins occupy northwesterly striking fractures. Within the veins the sulphides form massive zones (Newcor), anastomosing stockworks (Cor, Bomber Lake) and vug fillings (Unity, Bomber Lake). In places they show a zonation. Where veins crosscut mafic volcanics, wall rocks are altered to fissile chloritic schist or chlorite-plagioclase-epidote schist; where quartz-porphyritic rhyolite is crosscut, as at the Unity occurrence, wall rock alteration is marked by development of chlorite and sulphides on the foliation planes.

The gold mineralization that postdates the Phantom Lake granite is of three main types: 1) volcanic-hosted carbonate-quartz-sulphide zones (Rio, Macmillan, Dee, Wekach Lake), 2) fracture-controlled quartz-sulphide veins in the Boot Lake pluton (Phantom Lake, Henning-Maloney, Yellow Jacket) and 3) fracture-controlled disseminated sulphide zones in the Phantom Lake granite (IMC).

The Rio deposit (Pearson, 1984; Middleton, 1985), which is representative of the volcanic-hosted deposits, lies on the Rio Fault (Fig. 3). The hanging wall of the fault comprises basaltic lavas and fragmental rocks, whereas the Boot Lake pluton and included basaltic rocks occupy the footwall or southeast side of the fault. Northeast of the deposit there is little alteration along the fault and shear planes are coated with chlorite and ankerite, whereas to the southwest the fault is marked by a zone of intense ankeritization, silicification and quartz veining. The Rio deposit occurs within a 90 m wide zone of carbonate-quartz alteration elongated along the trace of the fault, especially where included basalt is in contact with similar rocks in the hanging wall (Fig. 3). Within this alteration envelope there is no distinct fault plane, but rather a wide zone of fracturing.

The hanging wall orebody is a poorly defined zone of pyrite-gold mineralization grading 2 to 4 g/t Au in which gold values vary sympathetically with pyrite

[1]Economic Geology and Mineralogy Division, Geological Survey of Canada.
Project funded under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

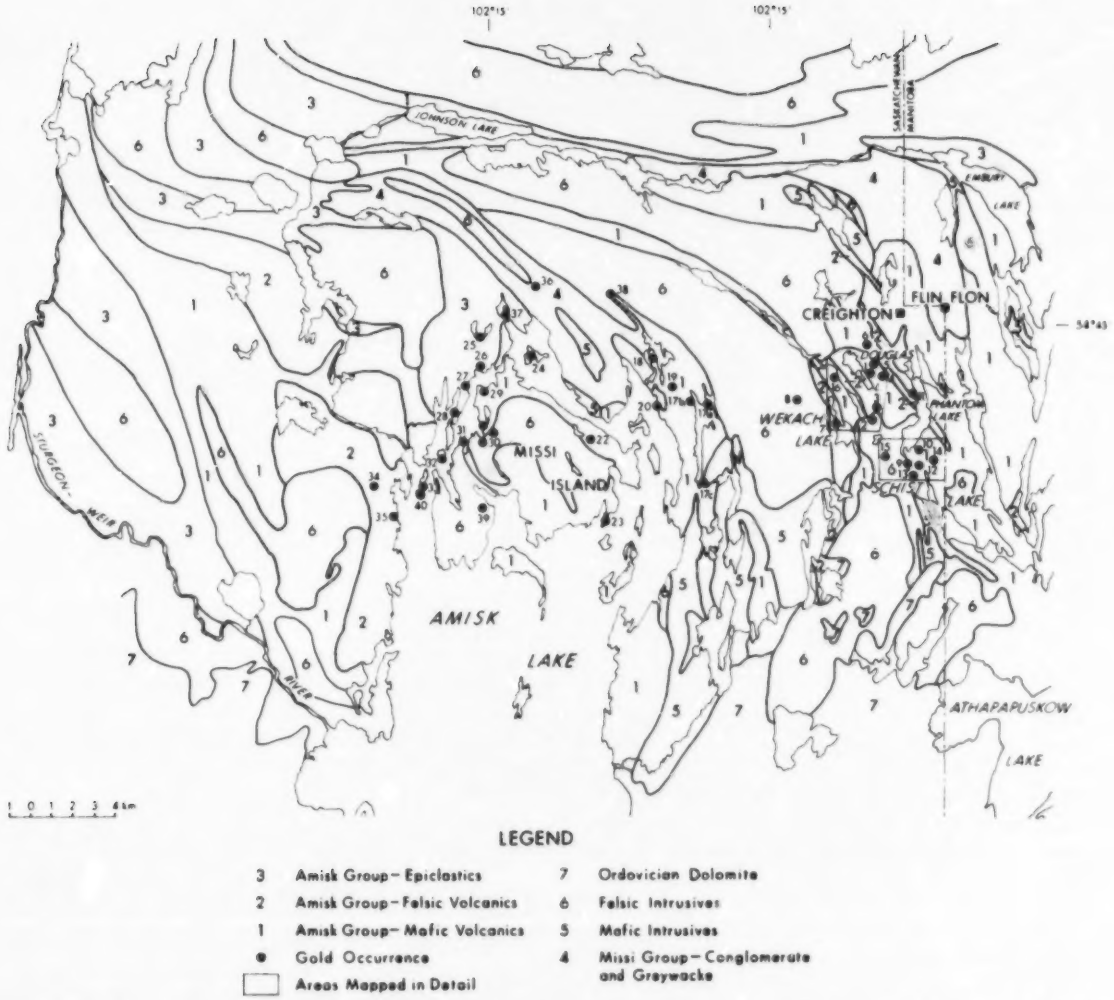

***Figure 1** - Geology and gold occurrences in the Flin Flon-Amisk Lake Area. 1, Newcor Mine; 2, Henning-Maloney Mine; 3, Rio Deposit; 4, Unity; 5, Cor; 6, Bomber Lake; 7, Wekach Lake; 8, Angelski; 9, Phantom Lake Mine; 10, MacMillan Mine; 11, North Phantom Lake; 12, Yellow Jacket; 13, Phantom-McRobbie Lake; 14, Dee; 15, IMC; 16, Dodo; 17a, Mosher Lake East; 17b, Mosher Lake North; 17c, Mosher Lake South; 18, Mitchell; 19, Sye; 20, Amisk Syndicate; 21, V.M. Group; 22, Derby (Hoodoo); 23, Lucky Strike; 24, Royal; 25, Kent; 26, Duplex; 27, Monarch Mine; 28, Amisk Gold Syndicate; 29, T.C.A.; 30, Laurel; 31, Beaver; 32, Hannay Island; 33, Waverly Island; 34, Wing; 35, Bud; 36, Graham Mine; 37, Golden Cross; 38, Robinson Creek; 39, Ace; 40, Sonora.*

concentration. Mineralization is commonly concentrated along zones or fractures trending at 170°. The lower or footwall orebody is of considerably higher grade (10 to 20 g/t Au) and comprises narrow (30 to 50 cm wide), massive, pyrite and quartz-pyrite veins also striking at 170°.

Type 2 gold mineralization is represented primarily by discrete gold-quartz-copper-tungsten-molybdenite veins in the Boot Lake pluton (Galley and Franklin, this volume). At the Phantom Lake mine it is hosted by a medium-grained hornblende granodiorite (Fig. 2). The granodiorite and adjacent porphyritic Phantom Lake granite are crosscut by two planar fracture sets, the older of which strikes west-northwest and north-northwest and the younger east-northeast and north-northeast. The veins are controlled by the older set of fractures, and do not appear to cross the contact with the Phantom Lake granite. Pyrite with minor chalcopyrite, arsenopyrite, sphalerite and molybdenite and accessory feldspar and purple fluorite occur in the veins.

Type 2 mineralization is also found as a vein stockwork in a 10 m wide zone striking parallel to the west-northwest fracture set. There appear to be at least three vein types striking roughly at right angles to the strike of the zone within the stockwork. Quartz-feldspar veins are crosscut by thinner quartz-chalcopyrite-pyrite veins which are in turn cut by even thinner quartz-chlorite-veins. Lower temperature alteration assemblages, consisting of epidote, pyrite, quartz, hematite and white clay, and controlled by

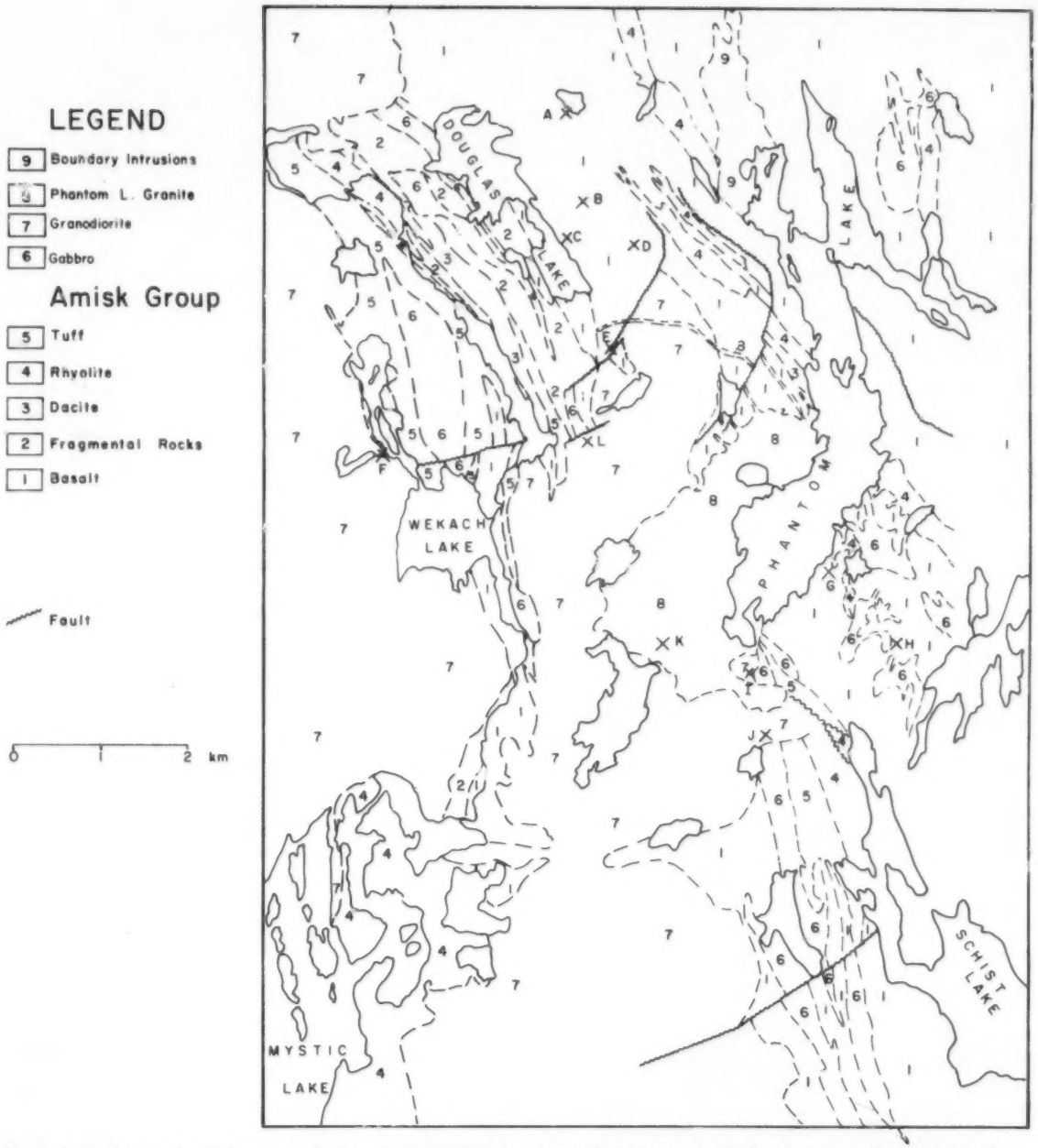

Figure 2 *- Geology and gold deposits of the Douglas Lake - Schist Lake area. A, Bomber Lake; B, Cor; C, Newcor Mine; D, Unity; E, Rio; F, Wekach Lake; G, MacMillan Mine; H, Dee; I, Phantom Lake Mine; J, Yellow Jacket; K, IMC; L, Henning-Maloney Mine. (after Stockwell, 1960; Byers et al., 1965; Pearson, 1979, 1991).*

the north-northeast/east-northeast fracture set, overprint the mineralization.

Type 3 mineralization is characterized by the IMC occurrence north of Boot Lake. Mineralization and associated alteration are controlled by northwest- and east-northeast-trending shears within the Phantom Lake granite. Along the shears there are 1 to 3 m wide zones of strongly foliated chlorite-carbonate-sericite rock containing boudinaged quartz veins. The foliated rock contains disseminated pyrite and chalcopyrite, while the veins contain pyrite and scheelite.

Amisk Lake Area

Stratigraphy

Interpretation of the stratigraphy in the Amisk Lake area is complicated by a lack of marker horizons and by complex tectonics.

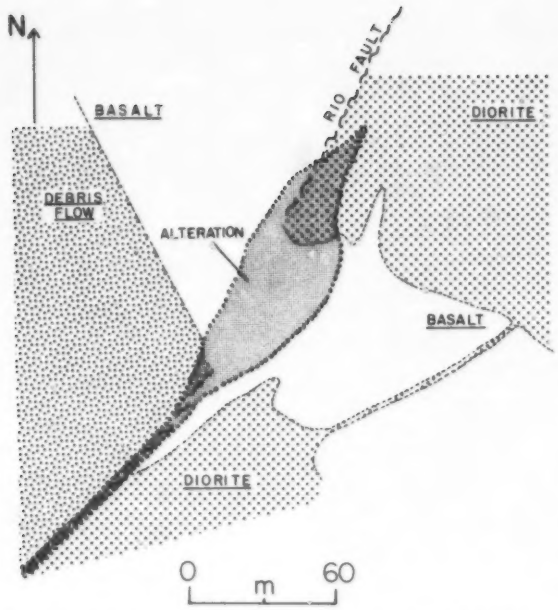

***Figure 3** - Geological sketch of the area around the Rio deposit.*

The lower part of the 'Amisk Volcano' comprises several kilometres of submarine basalts and associated breccias and fragmental rocks (Byers et al., 1956; Longeriau, 1980; Ayres, 1977; Ayres et al., 1981; MacDougall et al., 1979; Parslow and Gaskarth, 1984; Fox, 1976; Walker and Watters, 1982; van Wagoner and van Wagoner, 1981). It is overlain by abundant tuffs mixed with subaerial and subaqueous flows.

These rocks are folded by second deformation (P_2) structures with northerly-trending axial planes and disrupted by coeval north- to northwesterly-trending faults (Mosher Lake, MacDonald Creek, West Channel), typified by several parallel and tangential branches.

Gold Mineralization

Two types of gold deposits are present: 1) gold-quartz-carbonate-sulphide veins (Mosher Lake, Mitchell, Sye, Robinson Creek, Graham, Golden Cross, Duplex, Kent, Monarch Mine, Waverly, Sonora) and 2) disseminated gold-sulphide zones (Laurel Lake, Gull Island, Beaver and Amisk Gold Syndicate) (Pearson, 1980, 1983). Type 1 deposits, the gold-quartz veins, are invariably located along the flanks of major faults, as at the Monarch Mine, Sonora, and Robinson Creek, or within minor subsidiary faults, as at the Graham mine, Duplex and Golden Cross. Deposits occur variously within Amisk Group and Missi Group rocks; however, despite a wide variety of host rocks, the associated alteration is remarkably consistent and typified by development of pervasive iron carbonate (ankerite) and fine-grained silica-sericite-tourmaline. In the most intensely altered zones (Sye, Mosher Lake South, Robinson Creek-Bleiler zone (Pearson, 1982, 1983)), the host basalts are transformed to a very fine grained, fissile, grey, carbonate-chert rock and fractures are filled by quartz and quartz-carbonate veins.

The two deposits in the Missi Group (Robinson Creek, Graham) are typical gold-quartz-carbonate vein systems developed in proximity to major faults (Pearson, 1982, 1983). Veins are folded by second phase structures suggesting that the main period of gold-quartz vein formation was coeval with or postdated faulting, but occurred prior to the major second-phase folding.

Type 2 deposits occur in the West Channel Area of Amisk Lake. Around Laurel Lake and Gull Island (Fig. 4) the lowest part of the stratigraphic sequence is exposed as massive, pillowed and variolitic basalts. These are intruded by massive quartz porphyry which in the area west of Laurel Lake is flanked by crystal and lapilli tuffs grading into fine ash tuff. The felsic tuffs are in turn overlain by a thick sequence of fine-grained, bedded to laminated mafic tuffs. These rocks are folded by northerly-plunging upright P_2 folds with steeply dipping axial surfaces, and cut by a series of north- and northwesterly-trending fractures which are subparallel and tangential to the West Channel Fault system.

Within this setting there are a number of gold occurrences showing a variety of different accessory minerals. Thin veins of massive calcite-quartz-gold±pyrite±pyrrhotite±chalcopyrite±sphalerite±galena are present in fractured basalt, whereas in quartz and quartz-feldspar porphyry there are zones of disseminated fine-grained pyrite, gold mineralization. Associated with this fracture-controlled mineralization is an intense iron carbonate and sericite alteration characterized by disseminated magnetite (partially altered to hematite) and chlorite-filled fractures. In massive quartz porphyry, vuggy fractures are lined with pyrite, tetrahedrite-tennantite, enargite and rarely gold. They are flanked by successive zones of fine-grained chlorite alteration and sericite alteration. Lapilli tuffs contain stratabound disseminated pyrite-gold mineralization, in which small lenses of sphalerite and green mica are developed. The mineralization is enveloped by a pervasive sericite and iron carbonate alteration and folded by second-phase structures (P_2).

Discussion

In the Douglas-Phantom Lakes area, the early generation of quartz-sulphide vein deposits was emplaced during the formation of second-phase northwesterly-trending fractures, prior to intrusion of the Phantom Lake granite. Veins lie within narrow alteration zones, have similar mineralogy and are commonly vuggy, indicating that they were introduced at rather shallow depths (Boyle, 1979). Brecciated veins in the Unity and Bomber Lake occurrences and the boudinaged nature of the Cor occurrence suggest intermittently active fractures.

The later generation of deposits is more complex.

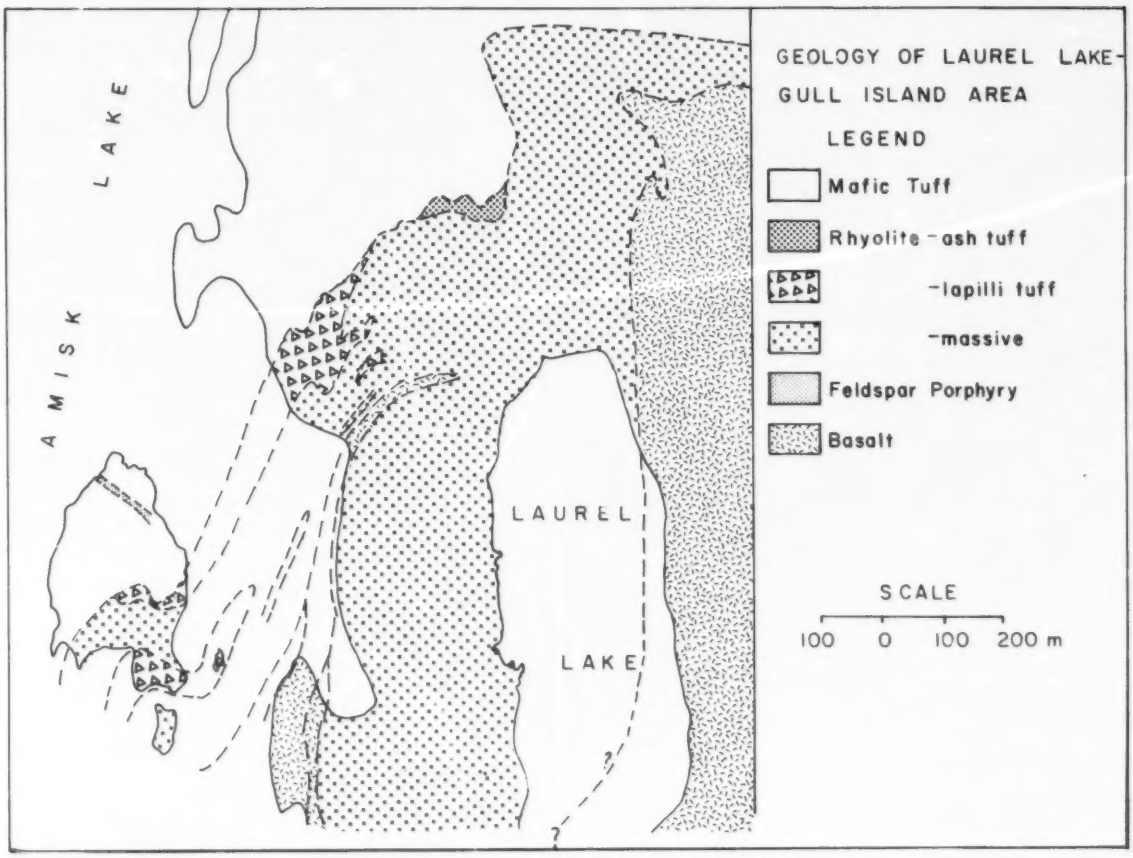

Figure 4 *- Geology of the Laurel Lake area in the West Channel - Missi Island area of Amisk Lake.*

Deposits show differing ore mineralogy, gangue mineralogy, host rock and alteration assemblages, but are consistent in postdating the Phantom Lake granite and apparently in containing tungsten. They are considered as a product of the same porphyry system.

Observations made at and near the Phantom Lake mine and the IMC deposit suggest progressive alteration, from high to low temperature, along successive generations of fractures. The older fractures trend west-northwest and north-northwest, and contain quartz, pyrite, chalcopyrite, arsenopyrite, molybdenite, feldspar and fluorite, as well as chlorite and scheelite. This type of mineralization does not appear to cross the contact of the Phantom Lake pluton. The later east-northeast and north-northeast fractures, containing epidote, pyrite, quartz, hematite and clay minerals, however, occur in both the Boot Lake and Phantom Lake plutons and indicate overprinting of potassic and phyllic alteration by propylitic alteration.

The Amisk Lake gold deposits all occur in extrusive volcanic rocks, subvolcanic intrusives and volcanogenic sediments. These rocks were variably fractured subsequent to, or contemporaneous with, the formation of the quartz porphyry (rhyolite) dome (Fig. 5) at Laurel Lake. Hydrothermal fluids followed the fracture conduits provided within the brittle dacite and rhyolite porphyries, altering and mineralizing them. They also percolated into the more porous beds within the flanking rhyolitic tuff horizons. Basalts underlying the felsic dome contain some base metal rich veins, the genesis of which may reflect a differing response to the same hydrothermal regime.

The fracture-controlled gold-quartz veins representing the other type of gold mineralization in the Amisk Lake area are also thought to be products of this primary hydrothermal system. Fluids followed the major fracture zones, which formed conduits or channelways and gave rise to the gold-quartz mineralization in response to falling pressure and/or temperature. These deposits must have formed in response to early movements along the major faults prior to the second-phase deformation. This infers that the hydrothermal system at Laurel Lake was active for an extended period of time prior to Hudsonian orogeny.

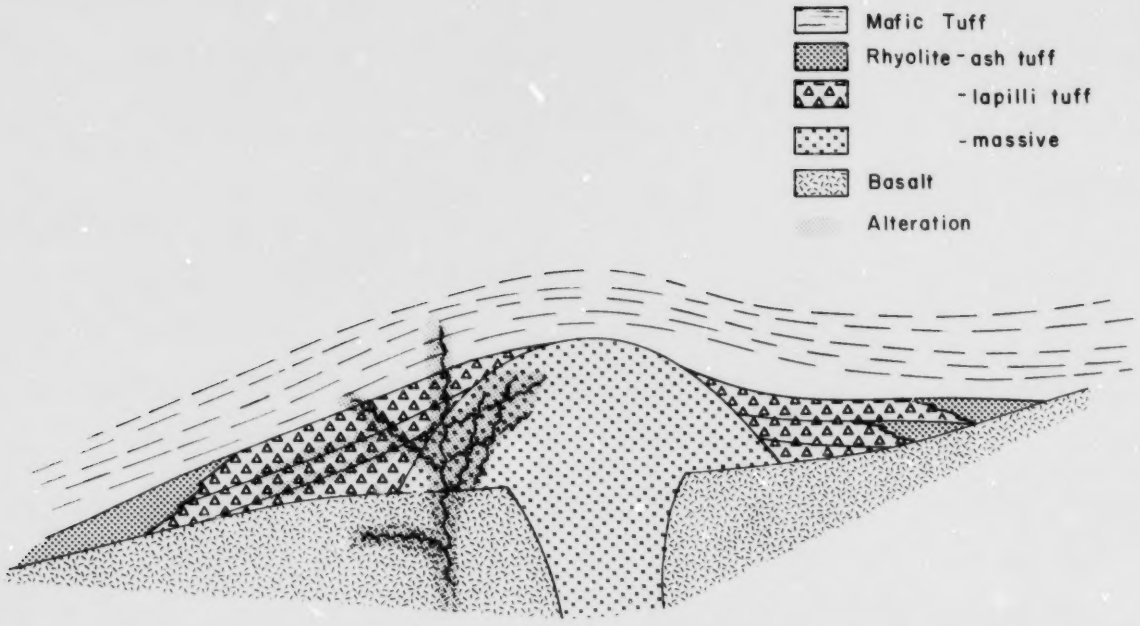

Figure 5 *- Schematic diagram illustrating the setting and controls of alteration and mineralization in the Laurel Lake area. Note that the alteration patterns follow fractures and porous beds within the fragmental apron flanking the quartz porphyritic rhyolite dome.*

Acknowledgements

Although much of this material has been presented previously, new observations and ideas, particularly from the Phantom Lake mine and the Laurel Lake deposit, by A.G. Galley of the GSC and F.H. MacDougall of SMDC respectively, have lead to new interpretations and a refinement of the previously presented hypothesis. A more complete description of this information will be included in a paper entitled "The Geology and Evolution of Gold Deposits in the Flin Flon - Amisk Lake Area" by J.G. Pearson, F.H. MacDougall and A.G. Galley to be included in the CIM volume "Gold in the Western Shield".

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MINERAL DEVELOPMENT AGREEMENT PROGRAM (CANADA COMPONENT)

Status of GSC Aeromagnetic Gradiometer VLF-EM Contract Surveys in Saskatchewan

by E.E. Ready[1]

Ready, E.E. (1985): Status of GSC aeromagnetic gradiometer VLF-EM contract surveys in Saskatchewan; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Saskatchewan 1984/85 Contracts

GSC Project No: 840068

Date of Award: September 18, 1984

Line Km: 4,778

Data acquisition completed: End of February, 1985

Compilation: 95 percent complete on all products (total field, VLF and gradient)

Delivery of Final maps: December 16, 1985 (estimated)

Maps released: February 1, 1986 (estimated)

No. of Maps: 1:20,000 - 11 total field and 11 vertical gradient (22 maps)
1:50,000 - 3 total field and VLF and 3 vertical gradient and VLF (6 maps)

Saskatchewan 1985/86 Contracts

GSC Project No: 840068

Date of Award: September 24, 1985

Line Km: 18,787

Data Acquisition: Contractor now on site at Flin Flon, Manitoba

Delivery of Final maps: May 31, 1986

No. of Maps: 1:20,000 - 20 total field and 20 vertical gradient (Sask).
- 8 total field and 8 vertical gradient (Sask-Man)

1:50,000 - 5 total field and VLF and 3 vertical gradient and VLF (Sask)
- 4 total field and VLF vertical gradient and VLF (Sask - Man)

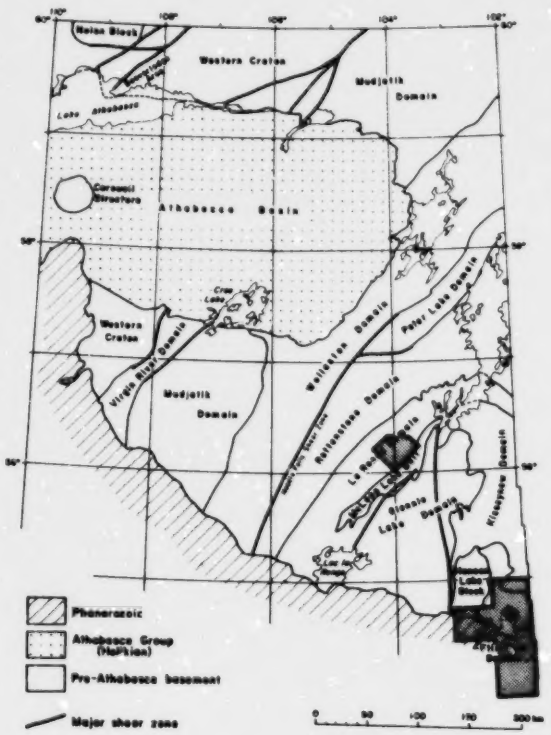

Figure 1 *- Areas covered by airborne gradiometric VLF-EM surveys in 1984-86 fiscal years.*

[1]Resource Geophysics and Geochemistry Division, Geological Survey of Canada.

Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Regional Reconnaissance Geochemical Lake Sediment and Water Surveys, Central Saskatchewan (Parts of NTS 73O, 73P, 74A, 74B and 74C)

by P.W.B. Friske[1]

Friske, P.W.B. (1985): Regional reconnaissance geochemical lake sediment and water surveys, central Saskatchewan (parts of NTS 73O, 73P, 74A, 74B and 74C), *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

A regional lake sediment and water survey was carried out under contract by the Geological Survey of Canada over 17,500 km^2 of central Saskatchewan (Fig. 1). The survey covered parts of NTS map sheets 73O (Ile-A-La-Crosse), 73P (Lac La Ronge), 74A (Foster Lake), 74B (Mudjatik) and 74C (La Loche), and is contiguous with previous regional lake sediment surveys released as GSC Open Files 266, 556 and 1129. Samples were collected from a total of 1152 sites for an average sample density of 1 site per 13 km^2.

Lake sediments will be analyzed for Zn, Cu, Pb, Ni, Co, Ag, Mn, Cd, As, Mo, Fe, V, Hg, U, Sb and LOI. Lake waters will be analyzed for U, F and pH. Survey results, to be released by early summer 1986 as a GSC Open File, will comprise sample location maps, sample value and site data ,and a summary of basic statistical parameters.

Sample collection for this year's survey was carried out under contract to Energy, Mines and Resources Canada by M.P.H. Consulting of Toronto. Helicopter services were provided by Okanagan Helicopters. Sample preparation was performed by Golder Associates of Ottawa. Lake sediment analyses will be performed by Barringer Magenta Laboratories in Toronto and water analyses by Barringer Magenta Laboratories of Calgary. Project coordination was provided by P.W.B. Friske of the Geological Survey of Canada.

The survey area encompasses parts of the Precambrian Rottenstone, Wollaston, Mudjatik and Virgin River Domains. Bedrock lithologies include amphibolite to granulite facies mafic to felsic intrusive and volcanic rocks, and mixed sedimentary rocks. The southern part of the survey area is underlain by relatively undeformed Paleozoic and Mesozoic sedimentary rocks overlying the Precambrian basement.

Mineral occurrences documented by the Saskatchewan Department of Mineral Resources[2] (1972) include uranium- and rare-earth element-bearing pegmatites, iron formations and mafic-associated copper and nickel mineralization.

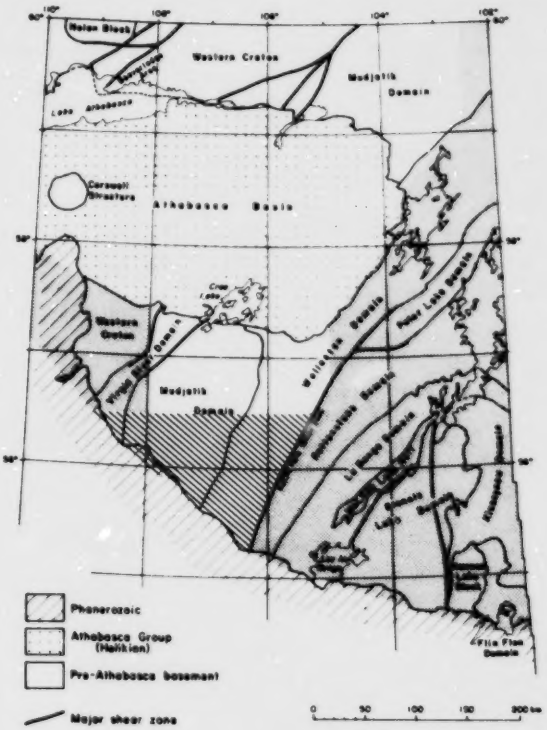

***Figure 1** - National Geochemical Reconnaissance Lake Sediment and Water Surveys, Saskatchewan. Dotted pattern, pre-1985 survey area; striped pattern, 1985 survey area.*

[1]Resource Geophysics and Geochemistry Division, Geological Survey of Canada.
Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

[2]Now Saskatchewan Energy and Mines.

Geochemical Follow-Up Studies Of Gold In Lake Sediments, East-Central Saskatchewan

by H.R. Schmitt[1]

Schmitt, H.R. (1985): Geochemical follow-up studies of gold in lake sediments; *in* Summary of Investigations 1985, Saskatchewan Geological Survey, Miscellaneous Report 85-4.

In 1974, a regional geochemical lake sediment survey was conducted in east-central Saskatchewan. The survey covered NTS map sheet areas 63M, 64D and parts of 63K, 63L, 63N, 73I, 73O, 73P and 74A at an average density of 1 sample per 13 km^2 over nearly 51,000 km^2. Analytical results were released as GSC Open Files 266 (Hornbrook et al., 1975) and 488 (Hornbrook et al., 1977) and reviewed by Hornbrook and Garrett (1976). Prior to 1984, the lake sediment samples had been analyzed for Zn, Cu, Pb, Ni, Co, Ag, Mn, As, Mo, Fe, Hg, LOI (loss-on-ignition), U (fluorometric) and U (delayed neutron counting).

In 1984 gold anlayses were undertaken on over 3500 of the archived samples collected during the 1974 GSC-DREE lake sediment survey of the southeastern part of the Saskatchewan Shield. The release of this gold data in May, 1985 on GSC Open File 1129 (Hornbrook et al., 1985) prompted a flurry of exploration staking activity, resulting in an area of over 690 km^2 of new claims.

Two areas from the La Ronge Domain which are anomalous in gold were selected for geochemical follow-up studies in 1985 (Fig. 1). The areas were chosen to represent a combination of bedrock/quaternary geology environments, proximity or absence of gold-bearing mineral occurrences, and coincident geochemical anomalies for elements such as As, Cu and Mo.

Objectives of Geochemical Follow-Up Studies

The general objective of the geochemical follow-up studies is to provide a better understanding of the factors which control the distribution and concentration of gold and its pathfinder elements in the lake sediment environment. Specific objectives include:

1) Outline the centre of the regional Au anomaly more exactly through detailed lake and stream sediment and rock geochemical sampling.

2) Examine and sample mineral occurrences in order to characterize their trace element associations and possibly establish Au-pathfinder relationships which are evident in the surficial environment.

3) Suggest procedures for interpreting and following up regional geochemical data which may benefit the mineral exploration industry.

Follow-Up Program

A) Waddy Lake Area - NTS 64D/4

The follow-up area covers about 130 km^2, 160 km northeast of La Ronge. Bedrock geology consists of a complex sequence of metavolcanics and metavolcaniclastics intruded by numerous ultrabasic to acid plutonic rocks (Harper, 1984). Glaciolacustrine sediments are widespread, generally below 440 m elevation, while a veneer of lodgement till occurs at higher elevations. The study area encompasses the Komis gold deposit as well as several other gold-bearing occurrences.

The following work was performed:

1) Detailed replicate lake-sediment sampling of Upper and Lower Waddy Lakes at a density slightly greater than 1 site/km^2.

2) Sampling of all stream sediments entering Waddy Lakes, and collection of a bulk stream sediment

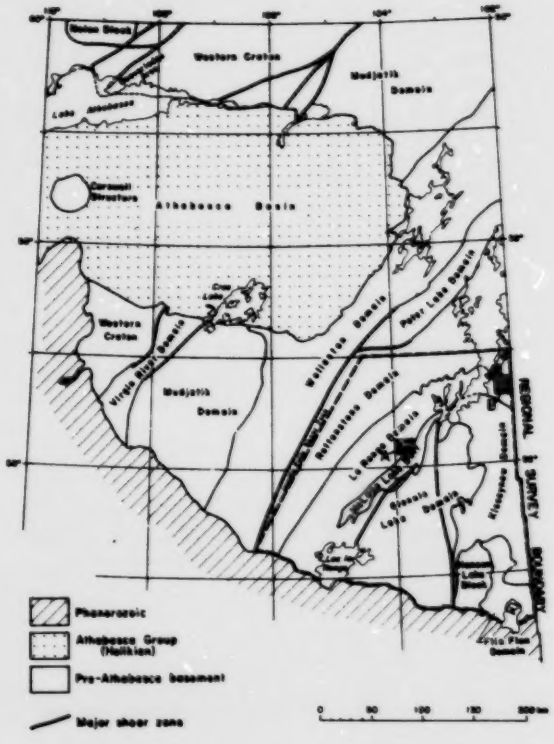

***Figure 1** - Location of geochemical follow-up surveys: A, Waddy Lake; B, Chancellor Lake. The 1974 regional geochemical survey area is delimited by the 'Regional Survey Boundary'.*

[1]Resource Geophysics and Geochemistry Division, Geological Survey of Canada.

Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

sample from a drainage south of the Byers Fault.

3) Sampling of mineralization and host rocks from several gold-bearing occurrences, and collection of key rock types from various locations for major, minor and trace element analyses.

Detailed fill-in and repeat lake sediment sampling west and east of Waddy Lakes was deferred because a helicopter was unavailable.

B) Chancellor Lake Area - NTS 64D/9, -16

This follow-up area covers about 190 km^2, with a core of 70 km^2 surrounding Chancellor Lake. The geology of the core area comprises biotite (± hornblende) quartz granodiorite with sparse inclusions of mafic volcaniclastics or metasediments, and a pendant of metapyroxenite. Pegmatite and aplite dykes are common. Sandy tills of variable thickness are the most pervasive surficial deposit. Mineralization is not documented from the area. Results from the regional geochemical survey indicate coincident anomalous Au, As and Mo.

The following work was performed:

1) Detailed replicate lake sediment sampling of Chancellor Lake by inflatable boat to achieve accurate positioning and a sample density greater than 1 site/ km^2.

2) Ground traverses adjacent to Chancellor Lake to examine and sample bedrock and till from catchment basins of lakes anomalous in gold.

3) Fill-in replicate lake sediment sampling of most of the study area utilizing Beaver and helicopter aircraft was completed. In parts of the area every lake was sampled.

Discussion

The results of the follow-up work are not yet available. Geochemical analyses will be performed during the winter (1985/86). An interpretation of the data will be aided by the results of ongoing detailed bedrock and quaternary geological investigations of the Saskatchewan Geological Survey and Saskatchewan Research Council.

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Hornbrook, E.H.W. and Garrett, R.G. (1976): Regional geochemical lake sediment survey east-central Saskatchewan; Geol. Surv. Can., Pap. 75-41, 20p.

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Hornbrook, E.H.W., Lynch, J.J., Friske, P.W.B., Lund, N.G. and Schmitt, H.R. (1985): Regional lake sediment geochemical reconnaissance data, east-central Saskatchewan; Geol. Surv. Can., Open File 1129, 145p (8 maps).

Structural Studies of Gold Mineralization in the La Ronge area

by K.H. Poulsen[1], D.E. Ames[1] and A. Galley[1]

Poulsen, K.H., Ames, D.E. and Galley, A. (1985): Structural studies of gold mineralization in the La Ronge area; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-5.

This sub-project was initiated in 1984. At that time it was widely understood that many of the gold deposits in the La Ronge area are localized by tectonic structures. This study was designed to investigate the structural controls of gold mineralization at all scales, in order to improve exploration models for this type of deposit as well as attain a better understanding of the processes leading to their formation. In the 1984 season, a pilot project was undertaken at the Starrex deposit where the association between gold and protomylonitic rocks was established. We expanded this study in 1985 to include 1:10,000 scale mapping of the Star Lake intrusion and its structural elements (50 percent completed), along with mapping at 1:500 scale of auriferous shear zones within it. In addition, we undertook pilot studies at the Seabee and Komis deposits. The report provides a summary of our preliminary findings.

Star Lake Deposits

The Star Lake intrusion, as mapped by Thomas (1984), is compositionally zoned (Fig. 1); diorite at its margins gives way inward to quartz monzonite and porphyritic granite (*sensu stricto*). The boundaries between the compositional types are largely gradational and our mapping has resulted in minor modifications (Fig. 1) of the zonation pattern; additional mapping will undoubtedly result in further modifications. The granitoid rocks are commonly xenolithic and are cut by numerous northeasterly striking mafic to felsic dykes.

There are at least three readily identifiable planar structural elements within the Star Lake intrusion:

1) a local compositional layering of probably igneous origin defined by modal variations in mafic and leucocratic constituents of the intrusion,

2) a weak to moderate metamorphic foliation defined by alignment of biotite grains and aggregates, as well as by the parallelism of long axes of deformed xenoliths, and

3) a superposed protomylonitic foliation which results from substantial reduction in grain size of original igneous constituents.

The protomylonitic foliation is restricted to discrete northeasterly striking, steeply dipping shear zones which are up to 30 m wide. These commonly comprise several anastamosed branches, each of which varies from 1 to 5 m wide. These shear zones are the fundamental structures which control the distribution of gold in the Star Lake intrusion (Fig. 1).

Quartz veins containing gold occur locally within the shear zones, commonly showing a cross-cutting relationship with the protomylonitic foliation, even though the veins, too, show evidence of some ductile deformation. Gold occurs with iron sulphides in the veins; coarse pyrite is the principal sulphide at the Starrex deposit, while pyrrhotite with lesser pyrite is common in the northern part of the intrusion. Calcite, scheelite, tourmaline, molybdenite, chalcopyrite and tellurides are present locally in variable amounts at different deposits. Sericitization of microcline is visible only within the mineralized zone at Starrex; this and the other deposits lack extensive wallrock alteration adjacent to mineralization.

The gold-quartz mineralization forms southwestward-plunging shoots within the shear zones. The amount of plunge is variable, ranging from 12^0 at the Decade mine to approximately 50^0 at the Starrex 21 Zone. These plunges are at a high angle to a prominent mineral lineation within the protomylonitic rocks. The plunge of the ore shoots is provisionally interpreted to correspond to an intermediate axis of strain, perhaps parallel to intersections of individual branches in a shear zone system.

Seabee Deposit, Laonil Lake

The Laonil Lake area is underlain by a complex of metamorphosed mafic to ultramafic rocks which are bordered to the south by a granodioritic pluton. Recrystallization to amphibolites has obscured the origin of these rocks to some extent, but coarse relict igneous textures, a common massive and homogeneous nature and the absence of unequivocal volcanic structures suggest that they are of plutonic origin, though some massive flow rocks could be present. The amphibolites are cut locally by granodiorite dykes.

Gold-quartz vein mineralization occurs within steeply dipping, northeasterly striking shear zones which deform both amphibolites and granodiorite dykes. The shear zones contain a steeply dipping foliation with a steeply plunging mineral lineation. Biotitic wall rock alteration is more extensively developed than at Star Lake. The biotite superposes the mafic host rocks and accentuates foliation in the shear zones by forming a crude tectonic layering. Individual shear zones at Laonil Lake appear to form branches of a much larger shear zone network.

[1]Economic Geology and Mineralogy Division, Geological Survey of Canada

Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

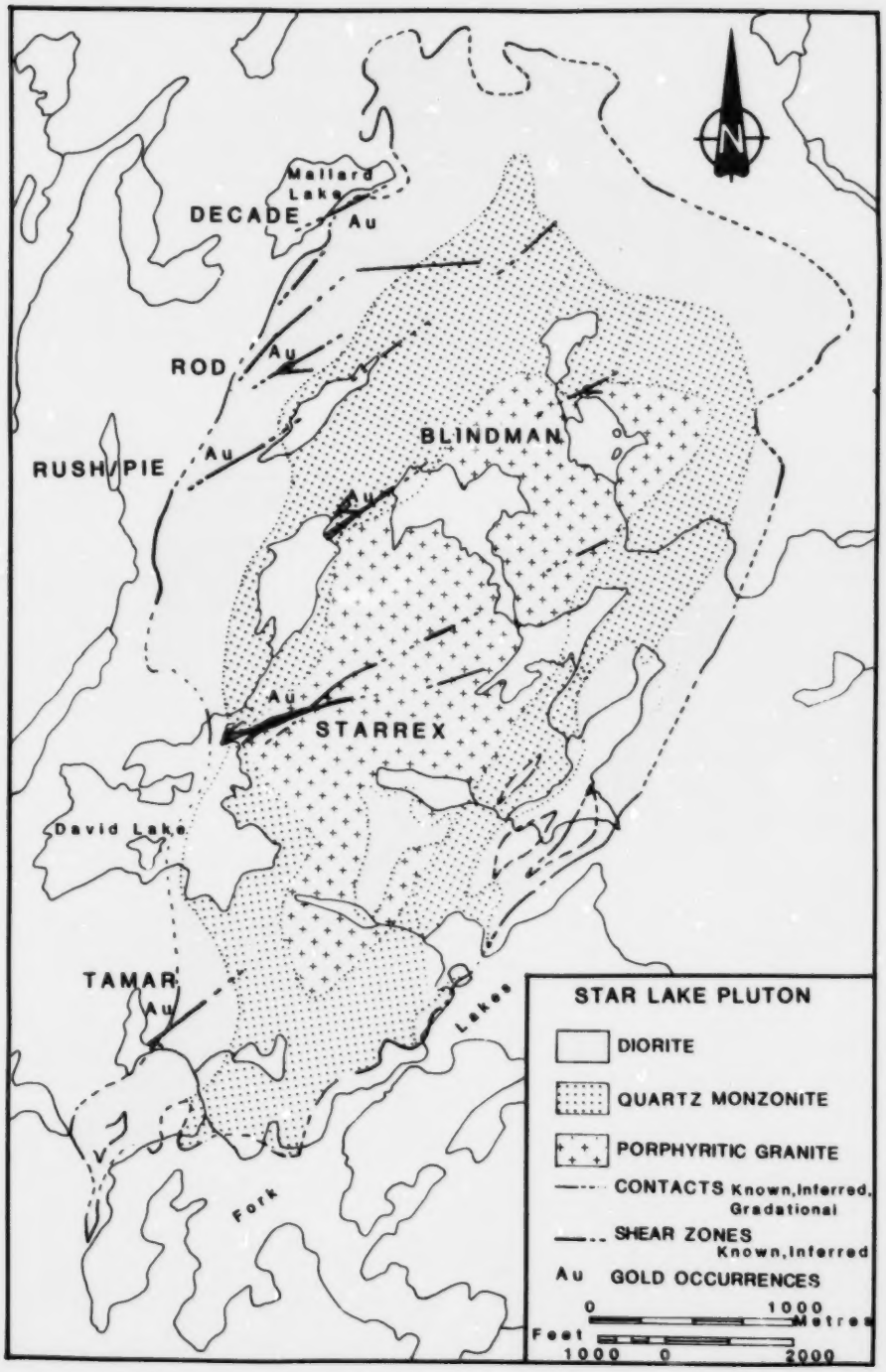

Figure 1 *- Shear zones related to gold mineralization in the Star Lake intrusion.*

Komis Deposit, Waddy Lake

The Komis deposit occurs within a hornfelsic metamorphic aureole developed adjacent to the Round Lake Stock (Harper, 1984). Unlike the deposits at Star and Laonil Lakes, there is no evidence of ductile shear associated with mineralization. Gold-quartz veins at the main Komis zone occur in arrays of *en echelon* northerly striking brittle extensional and shear fractures which transect all rock types including andesites, dacites and felsic plutonic dykes. Alteration haloes, in which the host rock is bleached and impregnated with pyrite, surround some veins. No anomalous foliation is developed in wall rocks adjacent to the Komis veins.

Summary

The exploration significance of our results is quite different for the Star-Laonil deposits in comparison with the Komis type. The former occupy structures which can be mapped, by recognition of anomalous foliation and lineation, even if the mineralization is not continuous within them; there is therefore an element of predictability in using structural mapping for exploration purposes. The Komis type of mineralization occupies brittle structures which have no manifestation other than the veins themselves. Structural mapping in this case, other than providing an understanding of vein orientation, is of considerably less value as an exploration tool. Plunge of shoots within all of these deposits is a critical factor in properly evaluating them.

Acknowledgments

Our studies have benefited from the generous cooperation of numerous industry, provincial Geological Survey and university geologists in Saskatchewan.

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Harper, C.T. (1984): Geological mapping, Waddy Lake area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p6-20.

Thomas, D.J. (1984): Geological mapping, Star Lake area; *in* Summary of Investigations 1984, Sask. Geol. Surv., Misc. Rep. 84-4, p21-31.

Gold-Tungsten Mineralization Associated with the Phantom Lake Granite, Creighton

by A. G. Galley[1] and J.M. Franklin[1]

Galley, A.G. and Franklin, J.M. (1985): Gold-tungsten mineralization associated with the Phantom Lake Granite, Creighton; *in* Summary of Investigations, 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Work on gold and tungsten occurrences in the region around Phantom Lake was initiated as part of a five-year program to study gold metallogeny in the Flin Flon-Snow Lake Belt. The project was begun during the 1984 field season when both gold and tungsten occurrences were examined in an area from Douglas Lake eastward to the east shore of Phantom Lake (Fig. 1). The relationship between gold and tungsten is of interest in understanding the processes involved in the formation of gold deposits.

General Geology

The gold and tungsten mineralization occurs within three different rock types: 1) the Amisk Group mafic to felsic volcanic rocks and associated sediments, 2) the texturally and compositionally zoned Boot Lake Granodiorite, and 3) the microcline-porphyritic Phantom Lake Granite. These rocks are all Aphebian in age, and range from 1.89 Ga for the volcanic rocks to 1.82 Ga for the Phantom Lake Granite, the latter being the youngest zircon age data determined in the Flin Flon-Snow Lake Belt (R. McQuarrie, pers. comm.).

The Amisk Group volcanic rocks have undergone at least three periods of folding and have been affected by two major sets of faults. The youngest faulting took place after the last period of folding, and is represented in the area by a system of high-angle reverse faults characterized by the Cliff Lake Fault (Fig. 1). The emplacement of the Phantom Lake Granite, and possibly the Boot lake Granodiorite, is thought to be controlled by this late fault set, even though the intrusions are cut by fractures of this set.

Mineralization

During the course of the first season of field study, several general observations were made:

1) Gold-related mineralization is fracture and fault controlled.

2) Gold mineralization is present in structures that cross-cut three distinct ages of rock: the Phantom Lake Granite, Boot Lake Granodiorite and Amisk Group volcanic and intrusive rocks.

3) There appears to be a spatial relationship between gold-copper-tungsten-molybdenum occurrences and the Phantom Lake porphyritic granite.

4) The Au-Cu-W-Mo metal associations and attendant phyllic, argillic and potassic alteration assemblages present in many of these occurrences are characteristic of mineralization associated with high-level porphyritic felsic intrusions.

With these general observations in mind, structural and mineralogical data from the 1984 field season were analyzed to determine whether there were any comparisons or contrasts to be made among mineral occurrences in the area. The mineral occurrences in the area consist of vein systems within strong shear or breccia zones. The veins within these systems commonly display a consistent paragenesis, with higher temperature

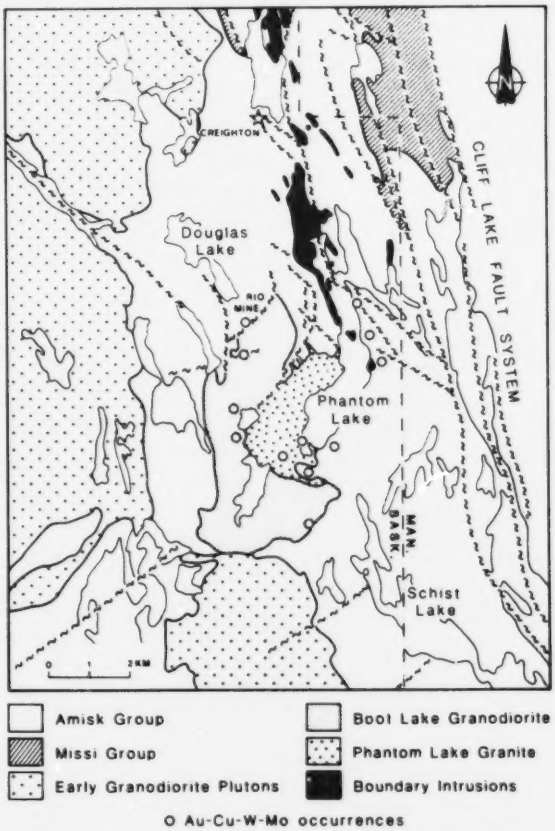

***Figure 1** - Au-Cu-W-Mo occurrences in the Douglas-Phantom Lakes area.*

[1]Economic Geology and Mineralogy Division, Geological Survey of Canada

Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

quartz-feldspar veins being overprinted by successive generations of veins containing lower temperature mineral assemblages such as quartz-hematite. The metal distribution appears to be controlled by the composition of the host rock rather than following any concentric zoning pattern around the Phantom Lake Granite. The fracture and fault systems that control the mineralization follow distinct patterns which appear to be related not only to the intrusion of the Phantom Lake Granite but also to the stress field responsible for the formation of the Cliff Lake Fault System.

Summary

During the 1985 field season, more time was spent in the Phantom Lake area. The work included examination of several additional mineral occurrences, as well as recording of numerous fracture and shear orientations in the area between the West Arm Mine Road and the east shore of Phantom Lake. It would appear now that the Boot Lake Granodiorite may be of similar age to the Phantom Lake Granite, and it is possible that the intrusions may be genetically related.

Tentatively, the Au-Cu-W-Mo mineralization in the region around Phantom Lake can be related to the late, possibly anorogenic, Phantom Lake/Boot Lake intrusions. The relationships seem similar to porphyry-type mineral deposits of the southwestern United States.

Ni-Cu-PGE Mineralization Associated with the Rottenstone Lake Harzburgite-Pyroxenite Intrusion, Saskatchewan: Preliminary Findings

by L. Hulbert[1]

Hulbert, L. (1985): Ni-Cu-PGE mineralization associated with the Rottenstone Lake harzburgite-pyroxenite intrusion, Saskatchewan: preliminary findings; *in* Summary of Investigations 1985, Saskatchewan Geological Survey, Saskatchewan Energy and Mines, Miscellaneous Report 85-5.

Work on the mafic-ultramafic bodies in the area around Rottenstone Lake was initiated as part of a five-year program to study the mineral potential of mafic-ultramafic intrusions in northern Saskatchewan. The project was begun in late August of 1984 and followed up by additional fieldwork during the 1985 field season.

The Ni-Cu ores at Rottenstone Lake, Saskatchewan are unique with respect to their precious metal values. Limited mining records, and assays conducted during the course of this study reveal that the Ni-Cu ores are better endowed, in terms of grams per tonne, in Pt, Pd, and Au than the classic platinum group element (PGE) ores of the Merensky Reef and UG2 chromitite horizons of the Bushveld Complex, South Africa. Unfortunately, all that remains of the rottenstone ore body is a totally excavated (now flooded) pit and limited records of the brief mining activity. Although the lack of good records and documentation hamper studies of Rottenstone, the apparently unique (for Canada) characteristics of the deposit make it important to gain as much hindsight information as possible about the deposit, for comparison with other potential Pt-group environments in Saskatchewan.

Geology and Mineralization

The Ni-Cu-PGE ore at Rottenstone Lake is confined to a harzburgite-othopyroxenite sill-like body. The body is approximately 55 m long, 37 to 50 m wide, 8 to 12 m thick, dips 30ºE and was reported to contain 50,000 to 60,000 tons of material grading 2 percent Ni, 2 percent Cu, 7.5 ppm Pt, and 5.14 ppm Pd. Richards and Robinson (1966) record that from Sept. 5 to Nov. 7, 1965, 5,500 tons of ore averaging 3.23 percent Ni, 1.83 percent Cu, 4.79 ppm Pt, 3.92 ppm Pd, 1.03 ppm Au and 6.85 ppm Ag were milled. In terms of Ni and Cu these values are reasonably close to the results obtained from a composite sample collected during this project, which contained 3.3 percent Ni and 2.4 percent Cu. The PGE and Au values for the same composite are: 75 ppm Ru, 190 ppm Rh, 7400 ppm Pd, 2900 ppm Pt, 120 ppm Os, 110 ppm Ir, and 940 ppm Au, confirming the high precious metal content of the deposit. To date seventeen samples from the mine site have been analyzed for fifteen major oxides, twenty-nine trace elements and seven precious metals. A further five samples from the Tremblay-Olson showings, 2 km south of the mine site, have been submitted for similar analyses.

The trace element analyses revealed that the rocks and ores are distinctly enriched in zinc, the mean value of thirteen sampled ultramafic rocks is 580 ppm. The eight harzburgites have a mean of 736 ppm and the five pyroxenites 328 ppm. Three pelitic samples have a mean of 156 ppm Zn. The low values associated with the pelite tend to rule out a country rock contamination mechanism to enrich the ultramafic samples. The mean for the ultramafic rocks is approximately 10 times that of harzburgites and pyroxenites from the lower zone of the Bushveld Complex and 20 times that found in peridotites studied by Gurney and Ahrens (1973) in a survey conducted on the zinc content of mafic and ultramafic rocks.

A detailed mineralogical and stable isotope investigation of material collected around the mine site and from the Tremblay-Olson showing has revealed some important petrological and genetic information concerning the Rottenstone ores.

To date the compositions of twenty-five olivines, fourteen orthopyroxenes, nineteen tremolites, one hundred and three chromitites, five micas and six graphites have been determined by microprobe analyses. The olivines were found to range in composition from forsterite 83.4 to 85.9 and coexisting orthopyroxenes range from enstatite 85.1 to 87.5. Enstatite values as low as 82 were found in the orthopyroxenites. The mineralogical composition, in terms of the Mg# (i.e. the ratio of Mg/Mg plus Fe^{2+}) of these coexisting phases reflects high temperature equilibrium. It was found that the forsterite content of the olivines does not vary with the amount of sulphide in the sample. This suggests that the olivines have not re-equilibrated at lower temperatures and, therefore, that the composition of the olivines can be used as an indicator of the degree of fractionation or 'primitiveness' of the magma from which they crystallized. The olivines are extremely depleted in Ni as a result of co-precipitation with a Ni-Fe-Cu sulphide melt. The scavenging effect of this melt has left the olivines, regardless of the amount of coexisting sulphide, with less than a quarter of the normal Ni content they would have been expected to have if a sulphide melt was not in competition with olivine for available Ni in the magma. Since olivines from sulphide-poor examples show the same characteristic, this approach could be used in other apparently barren ultramafic bodies to test for hidden ore bodies.

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Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Chemically, one of the most diagnostic phases from this deposit is chromite. It has an extremely high Fe^{2+}/Fe^{3+} ratio, high Al (20 to 50 percent) and relatively high ZnO (0.7 to 2.0 percent) contents. The zinc-rich nature of the chromite is reflected in the abnormally high whole rock zinc values. The Cr_2O_3 content varies from 17 to 43 percent. Chemically most of the chromite from this deposit is unlike that found in other ultramafic bodies hosting Ni-Cu ores. It is anticipated that this unusual chromite chemistry may help explain why these Ni-Cu ores are exceptionally rich in PGE and Au. The phenomenon could possibly be used as an exploration tool.

The only other silicate phases encountered in the Rottenstone deposit are tremolite, serpentine and phlogopite. The tremolite has a Mg# of 0.830 and usually forms after orthopyroxene.

Although Richards and Robinson (1966) noted the occurrence of graphite in the ore at the Rottenstone deposit, an important observation of the present study is the recognition of graphite in the silicates as well as the ore. The presence of graphite suggests that the magma crystallized under extremely reducing fO_2 conditions and raises an interesting question: Are reducing conditions a necessary prerequisite for PGE enrichment in sulphides or is carbon also an effective scavenger of precious metals under magmatic conditions, or are both processes working collectively? Regardless of the mechanism, the recognition of graphite is a vital clue, for this is the only common factor yet recognized in PGE-enriched intrusions (i.e. Bushveld, Stillwater, Norilsk, La Perouse), and can be used as an exploration guide.

Laboratory investigations during the past year have raised some serious doubts about what appeared to be obvious field conclusions concerning the genesis of the ores. Since the ultramafic body is enclosed in a graphitic pelite horizon known to contain stratabound sedimentary sulphides, it was initially inferred that the ores are a result of country rock contamination. However, S-isotope data from fourteen pyrrhotite separates reveal a mean value of 2.96‰ and a mean S/Se ratio of 2561. These values leave little doubt that the sulphur in the Rottenstone ores is mantle derived, and not the result of magma contamination from sedimentary-derived sulphur. At present, six samples of graphite are being analysed for their C-isotope signature. This should provide additional evidence concerning the petrogenesis of this intriguing intrusion.

Summary

Detailed mineralogical and chemical investigations of the Rottenstone Lake Ni-Cu-PGE samples have revealed some useful information concerning this body. It is felt that a similar approach to other bodies in northern Saskatchewan will provide a valuable database of information to draw from when trying to evaluate these bodies and will lead to a better understanding of the genesis of Ni-Cu and PGE deposits in general.

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The Kisseynew Gneisses of Saskatchewan: Preliminary Report

by K.E. Ashton[1] and Katherine Wheatley[1]

Ashton, K.E. and Wheatley, K. (1985): The Kisseynew Gneisses of Saskatchewan: preliminary report; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines; Miscellaneous Report 85-4.

The summer of 1985 marked the beginning of an intended four-year study aimed at better understanding the southern portion of the Kisseynew Gneisses in Saskatchewan. The Kisseynew Gneiss terrain was mapped mainly at 1:63,360 scale by the Saskatchewan Geological Survey prior to the mid-seventies, and the geology has been provisionally compiled at 1:250,000 scale (Macdonald, 1981; Johnston and Thomas, 1984). The study is designed to include a new compilation of previous work in the region and will be supplemented with new data being collected over three summers of field work. An attempt will also be made to correlate the stratigraphy of the Saskatchewan Kisseynew Gneisses with their counterparts in Manitoba.

The field work in 1985 was carried out by a two-person crew in an area extending about 25 km westward from the Manitoba boundary through Kisseynew Lake, and included a detailed study of Weetago Bay, Mari, Little Mari, Yaskowich, Cotteral and Wildnest Lakes. Since the object of the study involves trying to 'see through' the metamorphic overprint to determine the original rock types, much of the field work is being carried out on the shores of large lakes where the exposure is better. Pace-and-compass traversing was carried out to provide some continuity of data between the lakes.

General Geology

Seven major lithological units were recognized in this summer's area of study. Due to the rarity of well-preserved primary textures and structures, and the structural complexity of the region, relative ages have not yet been established for all of these units.

A widespread heterogeneous suite of rocks was observed throughout the area, most of which are characterized by the assemblage hornblende-garnet. This **hornblende-bearing suite** consists mainly of intermediate to mafic garnet-horblende-plagioclase ± biotite gneisses, clinopyroxene gneisses and quartz gneisses, but also includes minor amounts of locally garnetiferous amphibolite, biotite-quartz-feldspar gneisses, hornblende-bearing quartzofeldspathic gneisses and calc-silicate rocks. Exposed rocks range from homogeneous over several metres to well layered on a scale of centimetres. Most of the hornblende-bearing gneisses in the northern part of the area have been previously interpreted as calcareous metasedimentary rocks, including impure dolomites, marls and greywackes, based mainly on their locally well-layered character (Cheesman, 1956; Pyke, 1961). Farther south, however, a volcanic and pyroclastic origin was suggested for strikingly similar-looking rocks (Byers et al., 1965), presumably due to their apparent lateral transitions into rocks of the Flin Flon Domain (Byers and Dahlstrom, 1954). As the Kisseynew Gneiss terrain is stratigraphically and structurally complex, further study is necessary to resolve this problem. Since the hornblende-rich gneisses are so heterogeneous and appear to occur at several different stratigraphic horizons, they may have been derived by several different modes of origin. The composition and general appearance of many of these rocks, however, suggest that at least some were derived from intermediate to mafic volcaniclastic rocks, minor flows and their intrusive equivalents.

The hornblende-bearing suite is commonly found in contact with, grading into, or interlayered with widespread **psammopelitic gneisses**. These are generally graphitic garnet-biotite-quartz-feldspar paragneisses containing sillimanite or hornblende. The rocks are commonly grey to rusty weathering, and are locally well layered on a scale of centimetres or homogeneous over several metres. The unit is easily distinguished by its composition, which is generally quite uniform over large areas, and by the common presence of graphite and abundant pink euhedral garnet. These psammopelitic gneisses are interpreted as metamorphosed greywackes and minor calcareous greywackes, and are thought to be correlative with part of the Nokomis Group in Manitoba (Robertson, 1953; Zwanzig, 1984).

A strongly deformed and metamorphosed **polymictic conglomerate** was found at several localities between Weetago Bay and Cotteral Lake. It is commonly juxtaposed between psammopelitic or hornblende-bearing gneisses and more mature psammitic rocks, but is discontinuous and cannot be traced for more than a few kilometres along strike. The conglomerate attains an apparent thickness of up to 500 m in the hinge zones of some folds but undoubtedly has also been thickened by early folding. It is strongly lineated and/or foliated and can easily be mistaken for a banded gneiss where a down-plunge orientation cannot be observed. The matrix is not easily distinguished from the clasts but appears to be of metamorphosed greywacke or calcareous greywacke composition and contains abundant garnet and biotite and/or hornblende. The clasts are mainly composed of rocks from the hornblende-bearing suite, including abundant intermediate hornblende ± garnet gneisses, minor garnet ± hornblende quartzofeldspathic gneisses, amphibolites and garnetiferous amphibolites. About 10 to 20 percent of the clasts are granitoid in composition. Most

[1]Geological Survey of Canada.
Project funded under the Canada component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

of these are fine to medium grained and contain feldspar phenocrysts, but rare clasts of medium- and coarse-grained equigranular granitic rocks and vein quartz are also present. No clasts of psammopelitic or psammitic gneisses were recognized. A metamorphosed polymictic conglomerate has been interpreted as marking the unconformable base of the Sherridon Group in the Kisseynew, Puffy and Nokomis Lakes areas of Manitoba (Zwanzig, 1984).

A unit of **psammitic gneisses** is also widespread throughout the area. These contain biotite, quartz and feldspar with varying amounts of garnet, magnetite, tourmaline, sillimanite, white mica or hornblende. Minor feldspathic quartzite is also included. The rocks are commonly white to grey weathering and can be quite homogeneous over several metres. Rare cross-bedding has been preserved locally but the degree of deformation minimizes the usefulness of these rare top indicators. Magnetite, coarse-grained red poikiloblastic garnet and/or tourmaline are distinctive in these rocks. The unit is found in direct contact with rocks of the psammopelitic unit but is more commonly separated from it by the polymictic conglomerate or by rocks of the hornblende-bearing suite. The psammitic gneisses are interpreted as metamorphosed arkoses and sub-arkoses and are tentatively thought to be correlative with part of the Sherridon Group in Manitoba (Bateman, 1944; Zwanzig, 1984).

The psammitic gneisses are locally interlayed with fine- to medium-grained foliated but **unlayered mafic rocks**. These are hornblende-plagioclase rocks containing garnet in places. The layers are rarely more than a few metres thick and rare apophyses were observed which cut across layering but are overprinted by the regional fabric, indicating a pretectonic intrusive origin for at least some of these rocks. They are interpreted as part of a suite of diabase dikes which may have other intrusive or extrusive equivalents in the region. Possibly related rocks include late metagabbroic plutons in the Mari Lake (Cheesman, 1956) and Wildnest Lake (Byers and Dahlstrom, 1954) areas and mafic volcanic rocks from the Sherridon Group (Zwanzig, 1984).

A widespread suite of white and pink, foliated to **gneissic granitoids** occurs as several large deformed plutons throughout the region. They mainly consist of biotite, quartz and feldspar, but garnet, white mica and hornblende varieties were also observed. Many contain relatively homogeneous cores but are rimmed by irregular zones of migmatite. These plutons generally appear intrusive and their locally peraluminous character is taken to indicate that at least some have an anatectic origin.

A swarm of syntectonic **pegmatite dykes** intrudes all supracrustal rocks. These white to pink, biotite-quartz-feldspar pegmatites locally contain tourmaline, garnet and/or white mica and are thought to be of anatectic origin.

Structure

The entire study area is intensely deformed and has been affected by several periods of folding. A well-developed gently dipping gneissosity produced during an early phase has obliterated almost all primary features. Large-scale structures associated with this early phase of deformation were not observed. The earliest recognized folds are tight, recumbent or near-recumbent, and fold the first-phase gneissosity. A strong colinear regional lineation was developed contemporaneously with this early folding, as well as an axial planar fabric which parallels the regional gneissosity everywhere except in the hinge zones of the early folds.

At least two phases of late open upright folding have produced interference outcrop patterns with the early phases, but this folding is not strong and the regional gneissosity has relatively shallow dips.

Other minor folding, at least some of which is associated with the boudinage of pegmatite dikes, is common on an outcrop scale.

Few faults were recognized in the area studied. Movement along some contacts of the psammitic gneisses is evident from the sheared fissile character observed at some outcrops. Late north-striking faults, characterized by chlorite- and epidote-filled fractures, were also recognized in the Weetago Bay and Wildnest Lake areas.

Discussion

It is clear from the present work that facies changes, unconformities, and structural complexities all greatly hinder any attempt to determine the detailed regional stratigraphy. It is unlikely that these problems can be resolved without further and more continuous detailed mapping. Although ideal marker horizons are lacking, distinctive horizons, such as the polymictic conglomerate and the contact between the psammopelitic and psammitic gneisses could be traced in detail. It is hoped that the structural information derived in this way will allow for a more confident and meaningful interpretation of the stratigraphy and geological history of the Kisseynew Gneisses of Saskatchewan.

Acknowledgments

In beginning geological work in any area exhibiting the complexity of the Kisseynew Gneiss terrain, it is particularly important to be exposed to the ideas of other more experienced workers. We have been particularly fortunate in this sense and are greatly indebted to several people for introducing us to the problems of the Kisseynew Gneiss region. Edgar Froese of the Geological Survey of Canada (GSC), John Pearson, Creighton Resident Geologist, of the Saskatchewan Geological Survey (SGS), Dave Price of the Hudson Bay Mining and Smelting Company and Ric Syme of the Manitoba

Mineral Resources Division (MMRD) all took time to show one of us (KEA) various localities of interest in the Flin Flon area. We also participated in a particularly enlightening field trip to Kisseynew Gneisses in Manitoba led by Hermann Zwanzig (MMRD), during which we were first introduced to the polymictic conglomerate thought to mark the base of the Sherridon Group. Geoff Parslow of the University of Regina and Bill Gaskarth of the University of Aston generously allowed us to accompany them on a tour of hornblende-rich rocks in the Mari Lake area and one of us (KEA) had the opportunity of examining a metamorphosed alteration zone in the Kisseynew Gneisses, courtesy of Bud Davis of Greenstone Resources.

Edgar Froese provided much-needed encouragement and advice during a mid-summer visit and Alain Leclair of Queen's University generously offered his assistance and helpful insights into the structure and metamorphism of the area during the month of September.

Special thanks also go to John Pearson for allowing us the use of his office facilities during the preparation of this report.

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OTHER NORTHERN STUDIES

Quaternary Geology of the Waddy Lake Area Applied to Prospecting for Gold

by Janet E. Campbell[1]

Campbell, J.E. (1985): Quaternary geology of the Waddy Lake area applied to prospecting for gold; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The Saskatchewan Research Council (SRC) has initiated a project in the Waddy Lake area (Fig. 1) to document such Quaternary geology conditions as the type, distribution and stratigraphy of deposits; the source of materials; and the direction and distance of transport. This information will be used to determine the most useful sampling media and the most effective techniques for drift prospecting.

The 400 km^2 study area, centred around Waddy Lake, coincides with the area of bedrock mapping being carried out by the Saskatchewan Geological Survey. This region of the La Ronge Belt was chosen because of the presence of known gold deposits and showings, and its complex Quaternary geology, which includes the presence of Lake Agassiz lacustrine sediments.

A summary of this summer's field investigations and some preliminary observations are included in this report, together with a preliminary map (Sheets 1 and 2, map pocket) showing the distribution of surficial deposits. The final Saskatchewan Research Council report, to be published at a later date, will include the results and interpretation of all work and analyses.

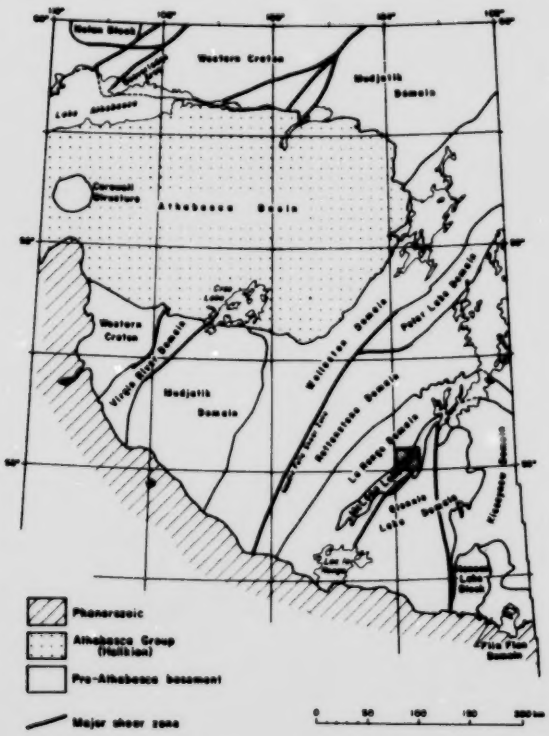

***Figure 1** - Location of the study area.*

Procedure

The first stage of the study involved the mapping at 1:20,000 scale of the deposit types and their areal distribution. Airphoto interpretation of the surficial geology was completed prior to the fieldwork. Ground-checking was carried out at 285 sites. Hand-augered holes or small pits were dug to an average depth of 80 cm at most of these sites. At six locations (WL-277 to 285), large backhoe pits expose sediments to a depth of 3.5 m.

Subsurface stratigraphic information was obtained by drilling 18 power-augerholes along the Waddy Lake access road approximately 1000 m apart at depths of 2 to 20 m, the average depth being 8.3 m. It is assumed that most holes reached bedrock, although this is not certain since the augerdrill cannot penetrate bedrock or very large boulders. Basal till was encountered in all but one hole. The information obtained from these holes will aid in characterizing the drift units and their mode of formation and will, in turn, be used to develop a model of the Quaternary geology for the area.

Representative samples of the various deposits were collected, but the main emphasis has been on sampling the till wherever it was encountered. Surface samples were taken from the C-horizon when possible. One hundred and eight bulk till samples weighing between 5 and 8 kg were collected throughout the study area, including 16 from augerholes. Surface bulk till samples were preferentially taken from the up-ice side of highlands, ridges and outcrops wherever possible.

General Geology

The areal distribution of surface material is shown on the accompanying surficial geology map (Sheets 1 and 2, map pocket). The approximate percentages by area of materials are: bedrock (30), glacial till (35 to 40), glaciolacustrine (15 to 20), organic (10), and glaciofluvial (less than 5). Based on information provided from the augerholes and exposures examined, the complete stratigraphy is:

6) Organic material
5) Brown silty till
4) Lacustrine sediments

[1]Resources Sector, Saskatchewan Research Council, Saskatoon.

3) Fluvial sediments
2) Grey sandy till (greenish to brownish)
1) Bedrock

Some or all of the units above bedrock are locally absent.

Bedrock

Outcrop is relatively abundant but is commonly masked by moss and lichen. The predominant rock types are metavolcanics, metasediments and felsic to intermediate intrusives (Harper, 1984). Weathered bedrock, in the form of *felsenmeer*, has been found around Round Lake. The undulating terrain of the exposed bedrock and the limited overburden drilling in the Waddy Lake area suggest a highly variable bedrock surface topography.

Glacial Till

Two tills previously detected in exposures and augerholes in the region (Schreiner, 1984) were confirmed during the present investigation.

The lower grey sandy till is commonly greenish-grey, dense, has a silty sand matrix and contains abundant granules and angular to subangular gravelly clasts, the last-mentioned forming 30 to 50 percent of the deposit. This till reflects the local bedrock lithology. A greenish-grey variety of this till is rich in volcanic rocks (mainly andesite), in contrast to a till originating from the pluton which tends to be brownish-grey and more sandy.

The upper till is thin and discontinuous and has been recorded at six sites. At two of these sites (backhoe pits WL-281 and 285), the till is less than 100 cm thick. At augerhole site WL-318, the till is over 3 m thick. The upper till is brown with a clayey to sandy silt matrix containing a lower percentage of smaller and more rounded clasts. The composition of this till reflects the incorporation of stratified sediments which have been overridden. This overriding is thought to be related to a minor readvance of ice into the Lake Agassiz basin (Schreiner, 1984).

Glaciofluvial Deposits

Less than 5 percent of the Waddy Lake area is covered by glaciofluvial sand and gravel. These deposits occur mainly in small channel-like depressions or as isolated kames. Just north of Rogers Lake, a kame complex includes several small eskers which form part of the lake's shoreline. Another large deposit is located around the gold deposit at Wedge Lake. Several sandy areas appear to be transitional between fluvial and lacustrine environments.

Glaciolacustrine Deposits

Clayey to sandy silt is the predominant glaciolacustrine material present although fine sand and clay are also found. The structure of these sediments is most commonly massive but laminated and/or varved varieties also occur at depth, as encountered typically in many of the backhoe pits and augerholes.

Glacial lake sediments are extensive but discontinuous. These sediments vary greatly in thickness, partly due to the rugged underlying topography. Permafrost is discontinuous but abundant in these sediments. Glaciolacustrine sediments were found at a maximum elevation of approximately 439 m (1440 ft.) in three locations. A cobble beach at approximately 457 m (1500 ft.) elevation is evidence of the highest lake level found to date. Several other beaches found in the Waddy Lake area occur at elevations ranging from 392 m (1285 ft.) to 450 m (1475 ft.). Washed and reworked till, and boulder lags also provide some indications of the extent of the glacial lake.

Organic Deposits

Most of the small lakes and major creeks and rivers in the area are bordered by wetlands. Muskeg occurs sporadically throughout the area. Three of the drier muskegs tested are relatively shallow (less than 100 cm thick) and are overlain by silts and clays or boulder lags. *Palsen* are present in some of the larger and wetter deposits, indicating the presence of permafrost.

Ice Direction Indicators

Numerous striae were noted on outcrops throughout the study area, ranging in direction from 188° to 205°, although 190° to 192° are the most common. These directions may represent more than one ice movement. Several *roches moutonées* with similar orientation have been found in this area.

Sample Analaysis

Characterization of the drift units by geochemistry, heavy minerals and pebble counts is included in the study. In addition, all samples are being subjected to textural analysis. At present, 158 till samples (including bulk till samples) have been analyzed at the SRC for copper, silver, arsenic, and gold. These samples were sieved to 0.1 mm (-150 mesh) and analyzed by atomic absorption. Heavy mineral separation of the bulk till samples is presently in progress at the SRC using a Wilfley Table and Superpanner. Samples are also being panned manually to separate the gold grains, which are then described and counted before the concentrates are assayed. The results from the gold grain counts and the geochemical and heavy mineral analyses will be compared to determine the most representative analyses. These analyses will provide background information for interpretation of mineral distribution (especially gold) in the tills, and will aid in the identification of the drift units most effective for exploration sampling.

Summary and Conclusions

Although few analytical results are yet available, several important preliminary observations can be made:

1) Two distinct tills are present in the area. The upper brown silty till is thin and very discontinuous. The basal or lower, grey sandy till is more prevalent. Variations in the lithology of the lower till reflect the variations in the local bedrock source, making it the preferred sampling medium.

2) Glaciolacustrine sediments are found at elevations as high as approximately 439 m (1440 ft.). The maximum lake level has been established by the presence of a cobble beach at 457 m (1500 ft.).

3) The rugged nature of the bedrock and till surface causes great variability in the thickness of the lake sediments.

Acknowledgements

The cooperation of the Saskatchewan Mining Development Corporation, Golden Rule Resources Ltd. and Goldsil Resources Ltd. in allowing access to their properties is gratefully acknowledged. Special thanks are given to Placer Development Ltd. for their assistance, cooperation and support during this summer's fieldwork, especially to Bill Pentland and Michael Gareau for their help and numerous fruitful discussions.

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Preliminary Assessment of a Microbiological Exploration Method for Gold In Boreal Forests

by Glenda Michaels[1], David Schneck[1] and Colin E. Dunn

Michaels, G., Schneck, D. and Dunn, C. E. (1985): Preliminary assessment of a microbiological exploration method for gold in boreal forests; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Traditionally, geochemical exploration for mineral deposits has involved sampling of various inorganic media with subsequent analysis for the desired element or its pathfinders. More recently, sampling and analysis of organic media, in particular various types of vegetation, have proven to be effective. Microorganisms, especially bacteria, represent another potential source of geochemical information.

Like larger organisms, bacteria are sensitive to the toxic effects produced by heavy metals. Many bacteria, however, are able to live in the presence of relatively high metal concentrations due to genetic tolerance mechanisms. These genes for metal tolerance, moreover, are activated at subtoxic levels (Summers, 1984), thus increasing the range of metal concentrations over which a microbiological exploration system can be utilized. Bacterial tolerances also operate over a wide range of metals and have been investigated for Sb, As, Bi, Cd, Cr, Co, Cu, Pb, Hg, Ni, Ag, Te and Zn (Clark et al., 1977; Foster, 1983; Gadd and Griffiths, 1978; Kelley and Reanney, 1984; Robinson and Tuovinen, 1984; Silver, 1981; Summers, 1984; Summers and Jacoby, 1977; Wood and Wang, 1983).

Because the toxicity of heavy metals imposes an evolutionary selection pressure influencing the microbial community (Campbell, 1981), metal-tolerant organisms should be found in greater concentrations where metals are present. This has been demonstrated in ecosystems polluted by heavy metals, and also in systems where silver nitrate or organomercurials are used as antiseptics (Albright et al., 1972; Babich and Stotzky, 1980; Barkay et al., 1985; Foster, 1983; Traxler and Wood, 1981; Troyer et al., 1980). Limited microcosm studies in the laboratory show a similar selection effect (Lighthart, 1980). Until recently, however, little attention has been given to the distribution of metal-tolerant bacteria in the vicinity of mineral deposits (Michaels and Riese, in press).

Of particular importance to mineral exploration programs is the fact that there is not always a direct correlation between soil chemistry and bacterial data. For example, there may be no apparent mercury enrichment in a soil, yet the bacteria may exhibit an increased tolerance to mercury. This tolerance may be linked to the development of a multi-element tolerance induced by the presence of another heavy metal (e.g., arsenic or tellurium). The latter may be related, for example, to gold mineralization.

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In effect, therefore, bacterial populations may give an indication of metal presence where conventional geochemical methods show none. In at least one case, microbiological studies by one of us (GM) have outlined a zone of uranium mineralization previously undetected by soil geochemistry.

Two areas in the La Ronge gold belt were selected for testing the application of microbiological exploration in the northern forests. A total of 16 samples duplicated at 8 sites were used for this orientation study.

Sample Locations

Duplicate samples were collected in the general vicinity of gold mineralization zones at:

1) **Sulphide Lake (Studer B Zone)** - Iron formation and quartz lenses contain pyrite, arsenopyrite and rare native gold (Coombe, 1984).

   Humus samples were collected a) close to known mineralization (near outcrop of arsenopyrite-bearing argillite), b) 250 m distant, and c) 3 km distant from the mineralization, representative of near mineralization, and at intermediate and background sites. Subsequent humus and vegetation analysis showed that arsenic is enriched at both 'mineralized' and intermediate sites (up to 63 ppm As in humus), but that gold enrichment is weak (up to 17 ppb Au in humus, and slightly higher in some ashed vegetation). The surficial geochemical data show the sites to be less distinct than anticipated.

2) **Star Lake** - Gold occurs in a pyritic quartz body within a shear zone transecting a quartz-monzonite phase of a felsic intrusion. Minor chalcopyrite and trace amounts of arsenopyrite and chalcocite are present (Murphy, 1985).

   Humus from a peat bog was collected near the 21 zone of mineralization. Both humus and A_1 soils were obtained from an intermediate site, and from a background site on a ridge of intermediate volcanics about 700 m west of the mineralized site. To date, chemical data have been obtained only from the mineralized site, showing that gold is enriched in the vegetation (up to 140 ppb Au in ash).

Field Procedure

At each sampling site the area was first cleared of leaf litter. A trowel was sterilized by pouring alcohol over its

surface and igniting. Samples of about 20 g were dug from the ground and placed in sterile Whirl-Pak bags, ensuring that the material was not touched, as this would contaminate the sample with micro-organisms on the sampler's hands. Care was taken to avoid over-heating of the samples and exposing them to direct sunlight, since high temperatures and ultraviolet light would kill some of the organisms.

Sample Preparation and Analytical Method

Removal of the bacteria from soil particles and debris is the first step in determining what proportion of the population is metal tolerant. A 10 g sample was aseptically removed from the sample bag using a flamed spatula and placed in 90 ml of 0.005M phosphate buffer in a screw-capped bottle. This measured dilution is necessary in order to accurately determine the number of bacteria per gram of sample.

Bacteria in the soil are most often clustered around mineral particles, organic debris and in the rhizospheres around plant roots, and are usually attached to various structures, but not all particles in the soil environment have a microbial population (Dommergues et al., 1978; Wimpenny et al., 1984). Because of the heterogeneous distribution, it is important to use samples larger than are necessary for adequate bacteria numbers alone, in order to obtain as representative a cross section of the bacteria present as possible. Although 1 g of soil will usually contain 100,000 bacteria or more, a 10 g sample gives a better representation of the population actually present in the soil.

The sample of soil in buffer was vigorously agitated for 1 minute using a vortex type mixer and then allowed to stand 10 to 20 minutes for settling of the larger particles. Subsamples were removed from the midsection of the bottle with a sterile pipet. The bacteria, being colloidal in size, remain in suspension while most of the particulate material settles. The suspension of bacteria was then tested for tolerance to selected metals.

Since gold tolerance has not been studied, three common pathfinder metals, cadmium, mercury and tellurium (as potassium tellurite), were utilized in the assay. Arsenic was not chosen because results have been less satisfactory for it than for other elements, due to complex reactions related to the tolerence of different bacteria to various chemical species of arsenic. Although Cd, Hg and Te are not known to be associated with gold in the study areas, the tolerance of bacteria to these metals could (as noted in the introduction) indicate the presence of other heavy metals in the environment.

At least two concentrations of each metal were utilized to determine tolerance levels. Although the relationship between tolerance and metal concentration is known for a number of laboratory strains (Foster, 1983; Silver, 1981; Summers, 1984), little information is available for strains obtained from the natural environment. Thus it is necessary to use several concentrations in order to obtain valid data.

Tolerance was determined by exposing the bacterial suspensions, obtained from the vortexing and settling procedure, to the selected metal concentrations in 0.005M phosphate buffer at room temperature. The use of buffer solution, rather than a growth medium, avoids the problems created by the binding of metals to medium components which are chiefly organic (Babich and Stotzky, 1980; Ramamoorthy and Kushner, 1977). Using buffer at a constant pH also eliminates variations in metal toxicity due to pH effects (Babich and Stotzky, 1980; Gadd and Griffiths, 1978).

After exposure to the metal solutions for 2 hours, duplicate 100 ul samples were removed from each metal concentration and assayed for surviving bacteria by the firefly luminescence method using 3M Corporation's Lumac system. This assay is based upon the specific enzyme reaction:

> luciferin + adenosine triphosphate (ATP) + Mg^{2+} + O_2 $\longrightarrow$ decarboxyluciferin adenosine monophosphate (AMP) + CO_2 + light (Karl, 1980; Leach, 1981; Webster and Leach, 1980).

The amount of light produced by the reaction is directly proportional to the amount of ATP present. Since bacteria, like all living things, contain ATP, which is not present in the abiotic environment, the amount of ATP present in the sample can be correlated with the numbers of bacteria (Karl, 1980; Kucnerowicz and Verstraete, 1979; Verstraete et al., 1983; Webster et al., 1984). Use of specific reagents in the assay procedure allows the ATP due to bacteria to be separated from that of any other organisms present in the sample (Karl, 1980; Verstraete et al., 1983).

Selected samples were also plated in triplicate on an agar-based medium for testing by the traditional cultural method in which survival is determined by the number of colonies developing on the medium after a period of incubation. Half-strength nutrient agar (Difco Laboratories) was utilized as the medium and the plates were incubated for 5 days at room temperature. The percentage of bacteria surviving in each case was taken as a direct measure of the tolerance of that population to the metal used.

Results and Discussion

The results from the initial set of humus samples as analyzed by the firefly luminescence method are shown in Table 1. These data indicate that virtually all of the bacteria present in these samples are unable to tolerate the metal concentrations utilized, and there is no difference between samples taken in the vicinity of an ore deposit and those from a distance. The parallel samples run by the traditional cultural method yielded a similar result. The cultural data also indicate that filamentous

Table 1 - Humus Samples from the Sulphide Lake Area (NTS 73P-7), Northern Saskatchewan, Assayed by Firefly Luminescence Method

Metal Conc. (ppm)	Site	Percentage Survival of Bacteria					
		240	*241*	*242*	*243*	*245*	*246*
none		100.0	100.0	100.0	100.0	100.0	100.0
Cd 100		3.3	4.2	3.7	4.2	3.8	3.5
Cd 250		2.4	2.0	1.4	1.5	1.2	1.0
Hg 1		6.7	6.1	6.1	6.5	6.0	5.7
Hg 5		5.8	6.3	6.1	7.0	6.0	5.9
Hg 10		6.7	6.5	6.5	6.7	6.0	5.9
Hg 20		6.4	6.2	6.5	6.3	6.0	6.7
Te 250		5.7	5.9	6.6	7.0	5.5	4.9
Te 500		5.2	6.1	6.5	7.0	5.5	4.7
Te 1000		5.6	6.0	6.5	7.0	5.3	4.7

Samples 240,241 taken near Au-As mineralization, Studer B Zone, Sulphide Lake (Coombe, 1984)
Samples 242,243 taken 250 m southeast of the Studer B Zone
Samples 245,246 taken 3 km to the west at the southeast corner of Lynx Lake

fungi are the most common microorganisms in these humus samples, a finding which is consistent with the literature (Dommergues et al., 1978; Gray, 1975; Wimpenny et al., 1984).

The lack of tolerant microorganisms in this humus/leaf litter type of sample is not surprising in view of the high levels of organic material which are present. Many naturally occurring organic compounds, especially humic and fulvic acids, have a high binding capacity for metal ions (Babich and Stotzky, 1980; Gadd and Griffiths, 1978) and may well remove metals to the extent that the microbial populations in this environment are minimally exposed.

When samples with less leaf material were analyzed, quite different results were obtained (Table 2). Very high levels of microbial tolerance were observed in these samples, especially in the one taken near Au mineralization. Moreover, there appears to be a decrease in the survival rates for samples from an area of no known mineralization (site 335) when compared with an area of low-grade Au occurrence (site 334). This trend is more obvious in the A_1 soils than in the A_0 horizon.

It should be noted, furthermore, that the sites selected for testing at Sulphide Lake (Table 1) proved geochemically less distinctive from one another than those at Star Lake (Table 2).

Concluding Remarks

The firefly luminescence assay was used because it appears to be an effective method for detecting microbial survival. It is rapid, simple to use, cost effective (about $10 per sample), and detects all of the bacterial populations. Traditional cultural methods, while often useful in the initial stages of developing an exploration program, detect only that portion of the bacterial population which will grow on the chosen medium. In aquatic systems, at least, the proportion of tolerant bacterial which will grow on artificial media is much less than that in the total population (Michaels and Riese, in press). Cultural methods are also slower, requiring at least 3 to 5 days for results. Uptake of radioactive isotopes is another method which can be used to detect bacterial survival (Albright et al., 1972; Jonas et al., 1984). Isotope methods do detect the entire population, but are slower and require a

Table 2 - Peat/Soil Samples from the Star Lake Area (NTS 73P-16), Northern Saskatchewan, Assayed by Firefly Luminescence Method

Metal Conc. (ppm)	Site	Percentage Survival of Bacteria				
		326	*334Ao*	*334A1*	*335Ao*	*335A1B*
none		100.0	100.0	100.0	100.0	100.0
Cd 50		85.0	50.0	56.0	45.0	53.0
Cd 100		60.0	42.0	43.0	37.0	47.0
Hg 5		88.0	32.0	53.0	58.0	40.0
Hg 10		68.0	30.0	43.0	53.0	36.0
Te 250		72.0	38.0	54.0	60.0	45.0
Te 500		72.0	29.0	62.0	53.0	45.0

Sample 326 - decomposed peat taken near Au mineralization
Sample 334Ao - humus taken near low-grade Au occurrence
Sample $334A_1$ - A_1 soils taken at same site
Sample 335Ao - humus where no Au occurrence is known
Sample $335A_1/B$ - soils from same site

laboratory with a liquid scintillation counter. These methods can be useful in providing comparative data during development of an exploration program.

The luminescence assay has certain problems, most of which can be overcome by modification of procedures according to the type of survey on hand.

Although few samples were used in this study, the data do suggest that a microbial system could be potentially useful for gold exploration in areas where soil samples of the A_1 or lower horizons are available. Given further development, the method may provide another tool to add to the more traditional methods of mineral exploration. Of significance, the microbiological method may be able to detect subtle haloes of heavy metals which cannot be readily detected by other methods.

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Biogeochemical Anomalies and Landsat Imagery: A Comparison in the Wollaston Lake Area, Saskatchewan

by Stan Aronoff[1], Colin E. Dunn[2] and George Reilly[3]

Aronoff, S., Dunn, C.E. and Reilly, G. (1985): Biogeochemical anomalies and landsat imagery: A comparison in the Wollaston Lake area, Saskatchewan; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Wollaston Lake (Fig. 1) is adjacent to the eastern edge of the Helikian clastic sediments that comprise the Athabasca Group. Numerous rich uranium deposits have been discovered at the Athabasca Group/basement complex unconformity (Fig. 2). Dunn (1982) conducted biogeochemical investigations which identified a uranium biogeochemical anomaly of exceptional magnitude and areal extent. Extensive sampling of the vegetation showed that black spruce (*Picea mariana*) is the species most sensitive to the presence of uranium. Spruce twigs were shown to be the plant parts that accumulate uranium most strongly, and the latest ten years of twig growth (less needles) was found to provide a practical amount of sample. Details of sampling and analytical methods are given in Dunn (1981). Using this method, work was conducted to define the extent of the Wollaston uranium biogeochemical anomaly. Twig samples from about 1000 black spruce trees were analyzed and a contour map of the biogeochemical data was produced (Fig. 2). The Wollaston uranium biogeochemical anomaly is defined by the 10 ppm uranium contour in ashed twigs of black spruce and extends over 10,000 km^2. The 50 ppm contour encompasses 3,000 km^2 and the 100 ppm contour 1,000 km^2 (Dunn, 1983a). Background levels are 2 to 4 ppm U.

The boundary of the Wollaston uranium anomaly does not appear to correspond to other geologic data. It was hypothesized that the spruce vegetation may exhibit some change in spectral response as a result of contact with uranium-rich water. The high concentrations of uranium found in the vegetation do not appear to be toxic. However, other elements associated with uranium might have an effect on the seasonal changes in reflectance of the spruce canopy. A cooperative study to examine possible changes in spruce canopy reflectance related to the Wollaston uranium anomaly was undertaken by DIPIX Systems Limited, Urangesellschaft Canada Limited and the Saskatchewan Geological Survey. The preliminary results are reported here.

Study Area

The Wollaston Lake area is in the boreal forest region of Saskatchewan. The area has cold winters and warm

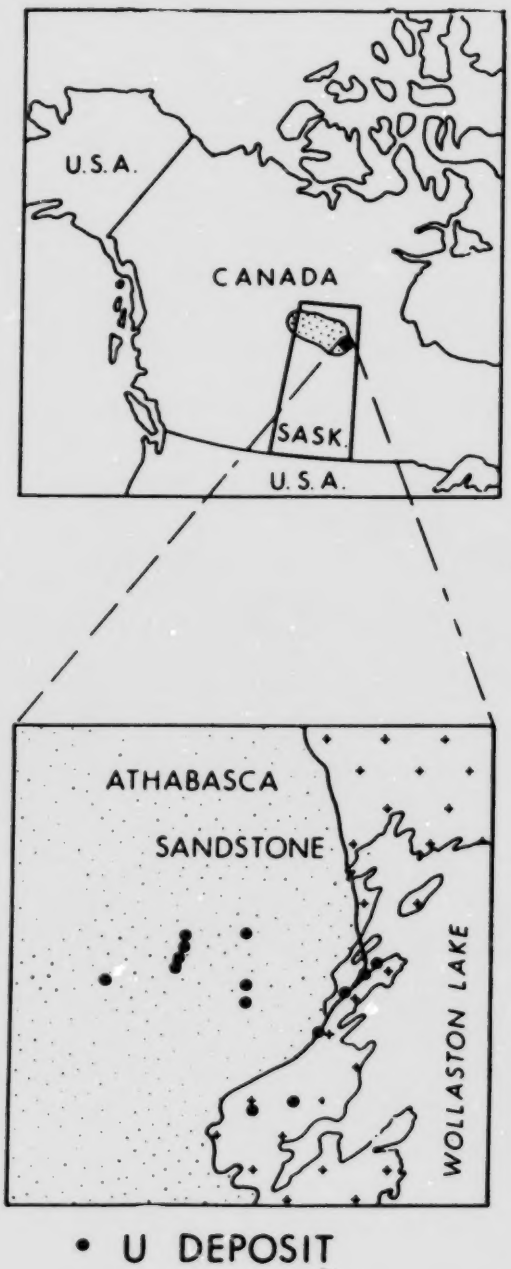

***Figure 1** - Location of the Wollaston Lake area and uranium deposits.*

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[3]Urangesellschaft Canada Limited, Suite 3100, 2 Bloor Street East, Toronto, Ontario M4W 2A8. Present address: 3139 Princess Blvd., Burlington, Ontario L7N 1G5.

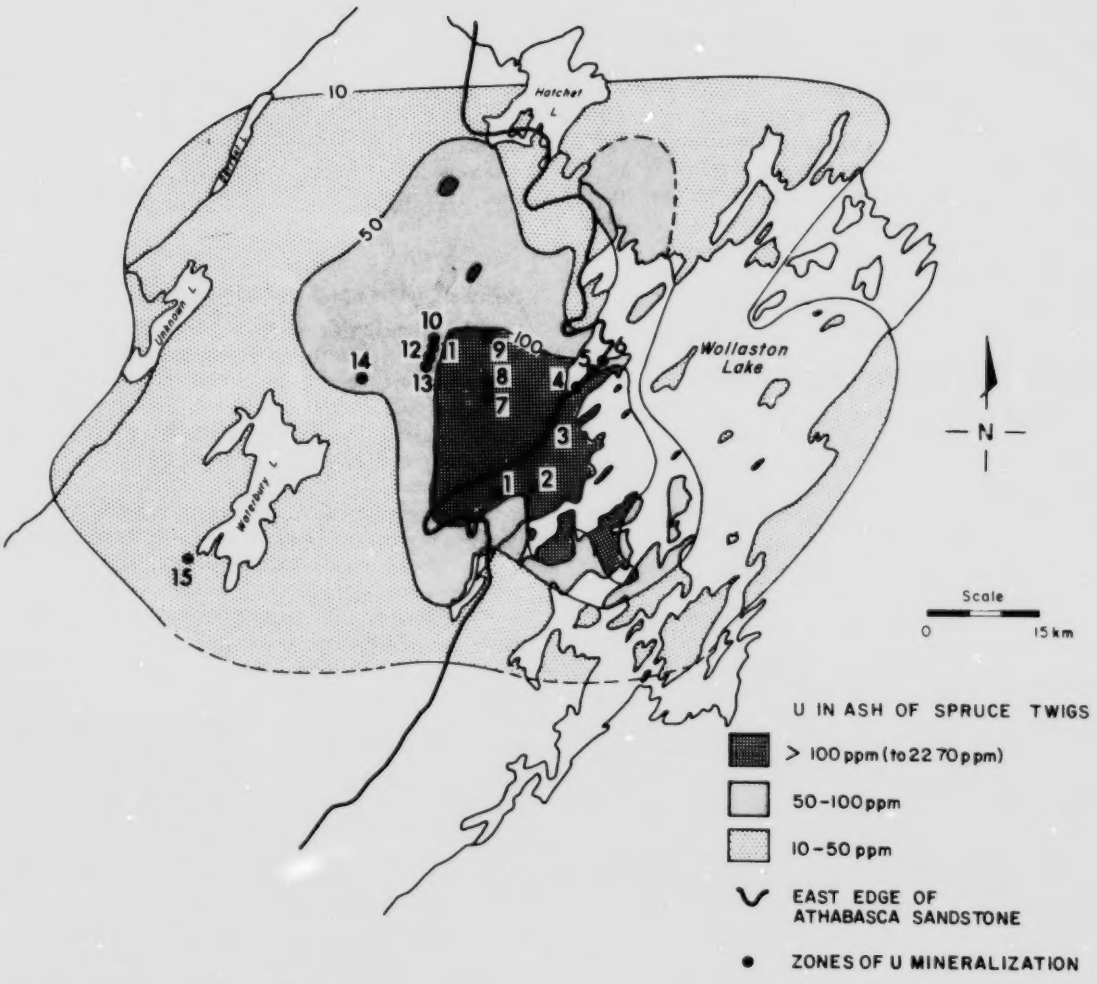


***Figure 2** - Extent of the Wollaston uranium anomaly (after Dunn, 1982). Names of the uranium deposits are: 1, Raven; 2, Horseshoe; 3, Rabbit; 4, Collins Bay A Zone; 5, Collins Bay B Zone; 6, Eagle Point; 7, McClean South; 8, McClean North; 9, JEB; 10, Dawn 14 Zone; 11, Dawn 11 Zone; 12, Dawn 11a Zone; 13, Dawn 11b Zone; 14, Midwest; 15, Cigar.*

summers with temperatures ranging from -50ºC to 35ºC. Annual preciptation is 40 to 60 cm, falling mostly in the summer. The area is in the zone of discontinuous permafrost. Vegetation is composed mainly of black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*); white spruce (*Picea glauca*), birch (*Betula Spp.*), poplar (*Populus Spp.*) and alder (*Alnus Spp.*) are common. The most common shrub species are Labrador tea (*Ledum groenlandicum*), leather leaf (*Chamaedaphne calyculata*) and blueberry (*Vaccinium Spp.*).

Geology and Uranium Mineralization

The Wollaston uranium biogeochemical anomaly (the 'Wollaston anomaly') is located in the eastern part of the Athabasca Basin (Fig. 2), which comprises gently dipping fluviatile sandstones of the Athabasca Group. The eastern part of the anomaly coincides with strongly deformed Aphebian gneisses and schists, containing granitoid rocks of both Aphebian and Archean age, which unconformably underlie the Athabasca Group. The anomaly covers the location of several major, high-grade uranium deposits of the unconformity type, but it does not correlate with any other known geological feature. The deposits lie along the Helikian - Aphebian unconformity, under as much as 400 m of Athabasca sandstone, and they appear to coincide in many cases with the intersection of the unconformity and late, northeast-trending faults which cut both the Helikian and Aphebian rocks. The deposits tend to be elongated in the direction of these late faults and they are considered to be epigenetic in origin. Very little outcrop exists in the area since bedrock is comonly covered by glacial sediments of Pleistocene age, usually a few metres but exceptionally as much as 90 m thick.

Pitchblende and coffinite are the most common uranium minerals, and some of the deposits contain appreciable amounts of a number of other elements including Ni, Co, As, Se, S and Fe. The main period of ore deposition occurred approximately 1300 Ma ago, and there has been extensive and continuous reworking of the deposits up to recent times. Ore deposition was accompanied by a characteristic hydrothermal alteration of the host rocks, particularly the Athabasca sandstone, in which alteration effects can be detected for distances of up to 400 m above the deposit (Clark, 1985), indicating extensive movement upward of mineralizing fluids.

Approach Used In The Landsat Analysis

In the field there is no obvious physical difference between the vegetation growing within the Wollaston anomaly and that in adjacent areas. Hence, it was considered unlikely that there would be any detectable difference in the Landsat data for fully developed summer vegetation between the anomalous and background areas. However, changes in a plant's environment can produce subtle changes in the timing of plant growth, reproduction and Fall senescence. The timing of these changes can be analysed using Landsat MSS data in a manner similar to the way crop calendars have been used for agricultural applications.

In this study, Landsat data were acquired for five dates in the same year (1974) with the same satellite, Landsat-1 (Table 1). After an atmospheric correction was made for each image, all images were registered to the summer image. The vegetation was classified so that comparisons could be made for a single vegetation type occurring inside and outside the area of the Wollaston anomaly. The August image was selected for classification because most of the vegetation is fully developed in mid-summer and the major vegetation types can be distinguished reasonably well. Pixel values were examined for each vegetation type for areas inside and outside the Wollaston anomaly.

Two hypotheses were investigated: 1) the observed anomaly would cause a change in plant development over time which could be identified by analyzing multidate imagery and 2) the anomaly would cause a change in the plant development cycle which could be observed in the data for a single acquisition date either in the spring or early fall.

To test (1) the reflectance values calculated from the Landsat data were plotted against time as represented by the five acquisition dates. Plots were produced for individual Landsat bands, band ratios and principal components. In respect of hypothesis (2), it has been reported in the literature that vegetation stress is most readily detected during the delay at the beginning of Spring green-up or during the onset of Fall senescence. In this study the best results were obtained with early Spring imagery.

Table 1 — Specifications of the Landsat-1 Data

Date	*Picture Centre*	*Frame - ID*
April 29, 1974	41 - 19	1645 - 17313
May 17, 1974	41 - 19	1633 - 17305
June 22, 1974	41 - 19	1699 - 17294
August 14, 1974	40 - 19	1752 - 17221
October 26, 1974	41 - 19	1825 - 17254

Results Of The Landsat Analysis

If the spectral reflectance of some plant species is affected by the Wollaston anomaly, this characteristic would have to be distinguished from other factors influencing the spectral reflectance of the vegetation. These factors were considered to be atmospheric effects, registration error and vegetation type.

Image processing was carried out using an ARIES Image Analysis System manufactured by DIPIX Systems Limited. Atmospheric effects were minimized by using an atmospheric correction routine which uses clear water bodies to calibrate the atmospheric model. Clear water bodies are well distributed throughout the study area, providing a good reference sample. Registration error was controlled by judicious selection of ground control points to give standard errors of less than 1 pixel. Resampling was done using a 'nearest neighbour rule', thereby preserving the original data values. Although cubic convolution might give a better estimate of a pixel value near a boundary, the smoothing effect was considered to be an unwanted source of variation.

Finally, variation in reflectance due to vegetation type was controlled by stratifying the image into vegetation classes using a supervised classification. The objective of the classification was to produce a vegetation stratum for coniferous trees. It is important for the class to be well distributed over the entire study area because the analysis of anomalies in vegetation development will only focus on pixels within the class. The classification would also have to be developed using one of the writers' field notes and experience, since the Landsat analysis was done several years after the field work and no additional field work could be undertaken. A look-up table classifier using Landsat MSS bands 5 and 7 was selected; this assigns a class only to pixels with the same digital value in both bands as one of the training set pixels. The class assigned is the class of the training set pixel it matches. As implemented on the ARIES system the classification is instantaneous, so that the class could be evaluated as additional pixels were added or removed from the training set. Only sites that had been visited in the field were used in the training set. Since the objective was to define a vegetation stratum to use as 'biological indicators', it was not necessary to assign every pixel to a class. Several vegetation classes were developed.

Preliminary analysis involved examination of Landsat data

values for pixels inside and outside the Wollaston anomaly for each vegetation type and each image data set. From this examination, it was decided to focus all further work on the 'Conifer' vegetation class as this class is well distributed over the entire study area. Morever, there appeared to be some systematic difference between pixels inside the Wollaston anomaly and those outside. The Conifer class used in all subsequent analyses is shown in Plate 1a and a scattergram of this class for the August image is shown in Fig. 3.

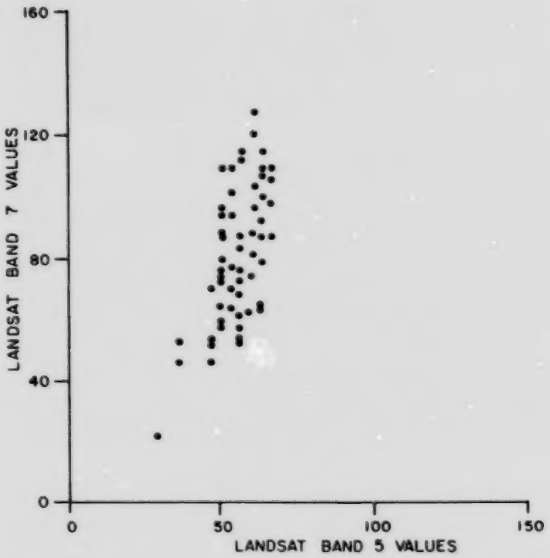


***Figure 3** - Scattergram of August image data for pixels included in the Conifer Class.*

It was recognized that this Conifer class represented several vegetation communities. Since coniferous trees in this area usually occur mixed with some deciduous vegetation, the Conifer class includes deciduous species. Coniferous trees show a change in reflectance value as they 'green-up' because the new growth of needles at the tips of the branches is lighter in colour than the older needles, although of course the green-up of deciduous vegetation is more pronounced.

In Plate 1b the boundaries of areas A, B and D correspond to the high, moderate and low uranium concentration classes in Fig. 2. Area C was shown in the low class in Fig. 2 and appears anomalous (see below) in the Landsat analysis. Since there were few field sample points in this area, area C was analyzed separately.

Table 2 shows a comparison of mean and standard deviations in band 7 of the May image for pixels in the Conifer class. In generating these statistics a mask was used to exclude pixels in areas obscured by cloud or cloud shadow, or covered by snow or floods. From these data it can be seen that although areas A and B (inside the Wollaston anomaly) have lower means than Area D (outside the Wollaston anomaly), the standard deviations are too high to give a statistically discernible difference in the means. Figs. 4 and 5 show the histograms for Conifer class pixels in the May band 7 image in areas A (highly anomalous) and D (background) respectively. The sharp peaks in the histograms are due to truncation of floating point values in the atmospheric correction and a linear stretch that left some bins empty and others containing pixels from two bins.

Curves were plotted for bands 5 and 7, the 7/5 ratio, and the first two principal components against image date for individual pixels. The shape of the reflectance curves does not appear to be related to the location of the pixel in the Wollaston anomaly.

The data for the Conifer class for each band were then examined to see if a threshold value could be selected which would divide Conifer class pixels into two groups corresponding to anomalous and background uranium biogeochemical areas. A value of 57 for the May band 7 image (11 percent reflectance) appeared to give the best result. The 'Anomalous Conifer' class pixels are shown in yellow in Plate 1b. Comparing this image to the map in

Table 2 — Comparison of May Band 7 Statistics for the Conifer Class

Area	*Mean*[1]	*Standard Deviation*	*Number of Pixels*
A	67.83	15.08	53533
B	67.17	14.52	102616
C	64.35	14.32	19980
D	78.66	14.86	101677
Full Image	73.14	15.70	368468

[1]units are digital number (DN) values which range from 0 to 255 for Landsat statellite data.

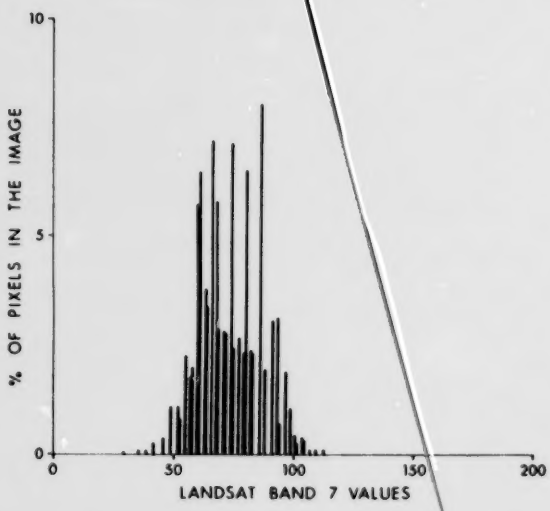
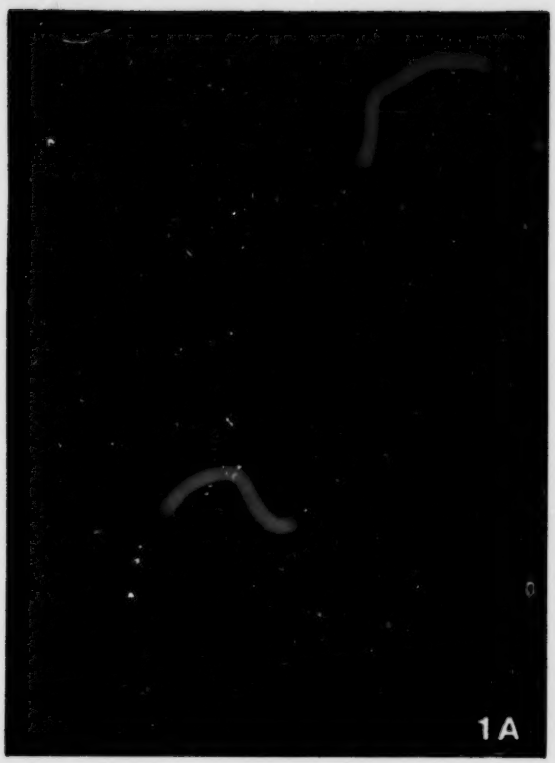
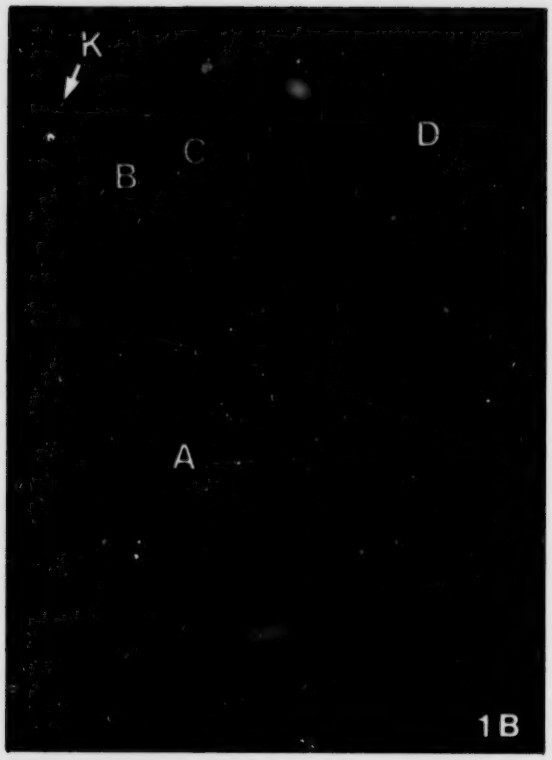


***Figure 4** - Histogram of pixel values in the Landsat Band 7 May image for Conifer Class Pixels in Area A.*





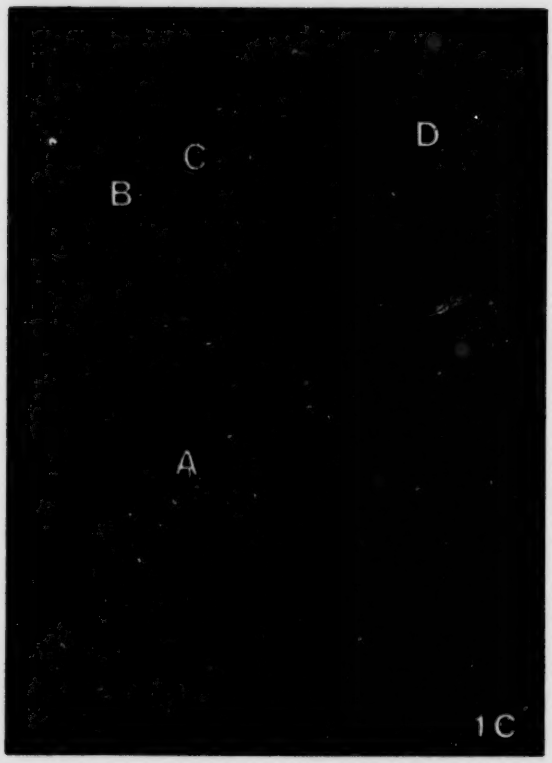


Plate 1A - Summer Landsat image of the Wollaston Lake area. Pixels included in the Conifer Class are shown in orange.

Plate 1B - Landsat image showing the boundaries of the Wollaston Anomaly. Conifer Class pixels subsequently classified as anomalous on the May Landsat image are shown in yellow.

Plate 1C - Landsat image showing Vegetation Class 13 as yellow.

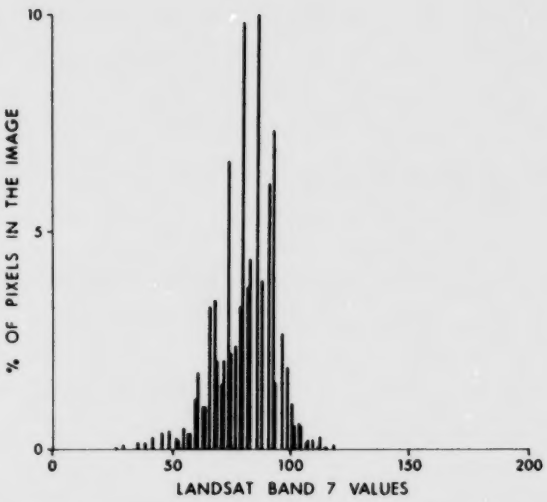


***Figure 5** - Histogram of pixel values in the Landsat Band 7 May image for Conifer Class Pixels in Area D.*

Fig. 2, the close correspondence between the Landsat analysis and biogeochemical analysis is striking. Although the Landsat analysis was in effect 'calibrated' using the biogeochemical field data, the very simple image analysis used to generate the anomaly class indicates a strong trend in the data. This trend was quantified as shown in Table 3. It can be seen that the proportion of Conifer class pixels in the Anomalous Conifer class is significantly higher in areas A, B and C than in area D or the proportion for the full image. Therefore the classification results appear to be significant, although the statistics of the image data indicate no significant difference among the band 7 means.

Table 3 — Proportion on Conifer Class Pixels Classified As Anomalous

Area	Number of Pixels: Anomalous/ Conifer Class	Number of Pixels: Conifer Class (n)	Anomalous Conifer: Conifer Ratio (p)	d[1]
A	14362	53533	.2683	.0049
B	27932	102616	.2722	.0036
C	7078	19980	.3543	.0087
D	7408	101677	.0729	.0021
Full Image	62184	368468	.1688	.0016

[1]Deviation for the confidence interval at the .01 level of significance was calculated as:

$$d = \frac{2.58\ p\ (1-p)}{n}$$

Delineation of the Wollaston Uranium Biogeochemical Anomaly

Having calibrated the Landsat representation of the Wollaston anomaly by comparison with field data, the analysis focused on the contribution the Landsat analysis could make to the delineation of the anomaly.

The shape of the Landsat anomaly corresponds well with Fig. 2 except in Area C. Since there were very few ground samples collected in this area and there was more confidence in the Landsat analysis, it was considered that the Landsat delineation of the anomaly in Area C was probably more reliable than the biogeochemical field data.

A number of strongly anomalous areas were identified in the Landsat analysis that had not been identified in the field. One such anomaly is shown at K in Plate 1b. As yet, field sampling of these new sites has not been undertaken.

In an effort to define a vegetation class in the August image occurring preferentially over the Wollaston anomaly, a second classification was done. The August Landsat bands 4, 5 and 7 data from pixels in the Conifer class were used to generate the statistics for an unsupervised 'maximum likelihood classification' of the full scene. Fourteen classes were produced, of which Class 13 appeared to be concentrated within the Wollaston anomaly area. Pixels in Class 13 are shown in yellow in Plate 1c. A comparison of the means and standard deviations of pixels in Class 13 in test areas A, B, C and D shows no statistically discernible difference. The occurrence of this class in each area was then compared with the total number of pixels classified as vegetation. The results of this comparison are shown in Table 4 and a scattergram for this class is shown in Fig. 6. Areas A, B, and C (inside the Wollaston anomaly) appear to have a significantly greater proportion of pixels in Class 13 than Area D outside the anomaly, or than expected from the full scene comparison.

Table 4 — Proportion of Vegetation Class Pixels Included in Class 13

Area	Number of Pixels: Class 13	Number of Pixels: All Vegetation Classes (n)	Proportion of Class 13 Pixels (p)	d[1]
A	10279	183467	.0560	.0014
B	18561	177734	.1044	.0019
C	5109	56701	.0901	.0031
D	6639	203812	.0326	.0010
Full Image	46198	1294287	.0357	.0004

[1]Deviation for the confidence interval at the .01 level of significance was calculated as:

$$d = \frac{2.58\ p\ (1-p)}{n}$$

Discussion Of The Landsat Results

There is a close correspondence between the Landsat vegetation anomaly as shown in Plate 1b and the Wollaston anomaly as mapped by Dunn (1982). This Landsat anomaly is the result of a lower band 7 value in

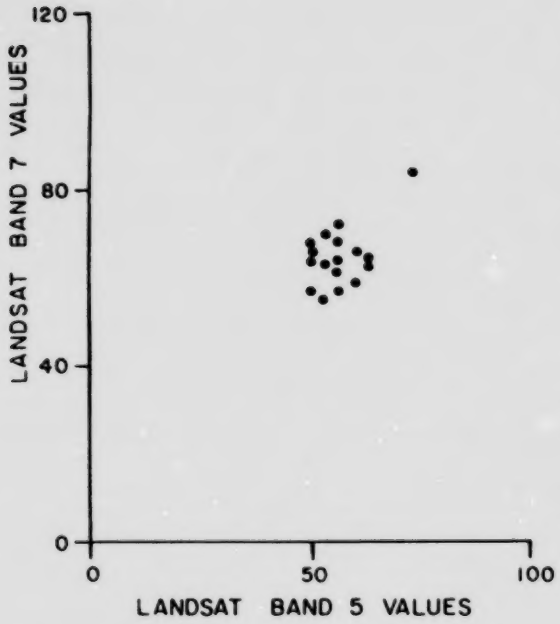


***Figure 6** - Scattergram of August Landsat Pixel Values for Vegetation Class 13.*

the May image for pixels in the Conifer class. MSS band 7 covers the 0.8 to 1.1 μm portion of the spectrum. Generally, as plant vigor increases the MSS band 7 value increases. One explanation for the observed Landsat anomaly is that vegetation in the Conifer class inside the Wollaston anomaly is stressed and tends to green-up later than Conifer class vegetation outside the anomaly. Possible mechanisms involved in this stress effect are discussed later. The classification algorithm used to define the vegetation stratum is a simple pixel value matching procedure and the anomaly is defined by a threshold value. The simple processing used suggests that the Landsat anomaly represents a real trend in the data and not a processing artifact.

Subsequent development of a class (Class 13), which appears to be a coniferous vegetation class, occurring preferentially inside the Wollaston anomaly suggests that there may be a vegetation community indicator for the Wollaston anomaly.

Origin Of The Biogeochemical Anomaly

A detailed analysis of possible sources of uranium in the vegetation and mechanisms to explain the anomaly are given in Dunn (1983a, b) and are summarized here:

1) Airborne Contamination

The only uranium mine within 300 km of the Wollaston anomaly at the time samples were collected (1979-1982) was that at Rabbit Lake (Fig. 2). This might seem a likely source for the uranium, especially since it is located in the heart of the anomaly. However, most sites with high concentrations of uranium in spruce twigs (500 to 1200 ppm U) are located 10 to 12 km northwest (i.e., upwind) from Rabbit Lake. Furthermore, over the past decade, the thirteen air-monitoring stations that surround Rabbit Lake indicate that the air is very pure and contains lower radioactivity than that over the Prairie Provinces and northern Ontario.

Studies have also shown that the uranium occurs within the structure of the twigs and is not coating the surfaces.

2) Soils and Glacial Drift

Commonly, there is a good correlation between trace metals in soils and vegetation. However, this relationship is not universal, because of varying physicochemical conditions and differential uptake of elements by different plants and plant organs. The distribution of uranium in soils of the Wollaston area bears no relationship to uranium in the plants. For example, 'B' horizon soils from 34 sites contain 2.3 to 3.2 ppm U, whereas ashed twigs from trees growing at these sites contain 5 to 886 ppm U.

3) Peat

The level of uranium in peat from the vicinity of the McClean deposits (Fig. 2) shows no correlation with uranium in the vegetation (Dunn, 1981). Conversely, detailed studies of peat in the area led DiLabio (1983) to believe that the vegetation does obtain its uranium from the peat, as concentrations in fresh peat are similar to concentrations in fresh twigs. If this is the case, several questions need answering, especially a) why uranium concentrations in peat are similar inside and outside the Wollaston anomaly, and b) why trees rooted in Athabasca bedrock or inorganic soils in the Wollaston area have similar uranium concentrations to those growing in peat. Peat does not seem to provide the answer.

4) Bedrock

Of the hundreds of holes drilled into the Athabasca sandstones, none have intercepted mineralization at a depth sufficiently shallow to be tapped directly by plant roots. In general, the bedrock contains less than 2 ppm U. Bedrock composition can, however, have a significant effect on the uranium uptake by the trees. For exanple, at the south end of Wollaston Lake, twigs from a tree rooted in podzol contain 86 ppm U, whereas 60 m away a tree in granite gneiss and pegmatite contains 253 ppm U. These differences are attributed to both the amount of labile uranium in bedrock fractures available to the roots and/or the presence of uranium dissolved in formation waters.

5) Waters

Surface waters and near-surface moisture contain sub-ppb levels of uranium. Formation waters, however, locally

contain tens of ppb U and exhibit an upward hydraulic gradient which is controlled by the dominant pattern of near-vertical fractures. Relatively permeable zones in the Athabasca sediments, in addition, give a horizontal continuity to water flow. The water table sits close to the surface.

These factors combine to provide a preferential upward movement of waters slightly enriched in uranium, along steeply inclined bedrock fractures. Some waters are dispersed laterally along permeable zones in the Athabasca sediments. Plant roots have access to these waters by directly tapping the near-surface water table or its capillary fringe. Uranium in solution is readily absorbed by millions of root tips, and translocated to the extremities of the spruce trees where it collects.

The result is a biogeochemical anomaly of extraordinary magnitude and lateral extent within which there are locally intense uranium concentrations in the vicinities of buried uranium mineralization.

Processes Which Might Induce Stress

It is not known whether uranium present in the vegetation is directly or indirectly responsible for the stress inferred from seasonal comparison of Landsat images. Associated with the uranium mineralization are numerous metals, particularly nickel and iron. Nickel is less mobile than uranium, and unusual nickel concentrations are not apparent in the vegetation. Iron, however, exhibits a moderately strong correlation with uranium in several plants (Dunn, 1981). Iron plays an essential role in plant growth, especially photosynthesis and nitrogen fixation (Kabata-Pendias and Pendias, 1984), and is not physiologically active in the ferric state, although it is often absorbed in this state and rapidly reduced to ferrous iron within plant cells in order to commence its role in the synthesis of chlorophyll. The rate at which iron is reduced in living cells is influenced by the quantity of manganese in the cells, since manganese acts as an oxidizing agent (Meyer et al., 1973). Thus, an excess of manganese may encourage the retention of iron in its physiologically inactive ferric condition. The result is mild stress, which could be manifested as retardation of vegetation green up.

These are known facts. The actual cause of stress in vegetation of the Wollaston area remains a subject of conjecture, and could result from:

1) simple mild toxicity of the vegetation by uranium;

2) the combined effect of iron and uranium, causing slight stress in the plants;

3) the additional effect of manganese (which is enriched in boreal vegetation, cf. Dunn, 1981) acting as an oxidant in keeping the iron in its physiologically inactive ferric state.

Iron is abundant in association with the uranium mineralization, and the Athabasca sandstone provides an oxidizing environment to maintain iron in its ferric state as it migrates with uranium in solution. The plant roots tap the formation waters containing these dissolved elements, and then struggle to convert the ferric iron to the ferrous state whilst manganese inhibits this reaction. Nature finally prevails in obtaining the essential ferrous iron in order that chlorophyll production can resume a little later in the year.

If explanation (3) is correct, there are important implications in the interpretation of Landsat anomalies in this environment. Anomalous areas may or may not reflect the presence of uranium in the vegetation, since the dominant effect may be stress-induced by the interaction of iron and manganese. In that uranium in the Athabasca environment is invariably associated with iron, the recognition of iron-stressed vegetation may be an important first guide to possible mineralization. Thus, the first step is a thorough Landsat investigation of an area. Subsequently, ground follow-up to ascertain the presence or absence of uranium in the vegetation is essential before embarking upon an extensive exploration program.

Conclusion

The vegetation analysis of Landsat data (Band 7) defined an anomalous Conifer class which corresponds closely to the Wollaston uranium biogeochemical anomaly previously identified by fieldwork. It appears that some vegetation types green up later in the spring when they occur within the Wollaston anomaly. No vegetation effects related to the presence of uranium have been reported in the literature on uranium toxicity; however, iron associated with uranium may be responsible for late green up. The Landsat analysis represents supporting evidence for the biogeochemical field study from an independent data source.

Sampling of other apparent Landsat anomalies to the west of the Wollaston anomaly will be a valuable test of the ability to discover new biogeochemical anomalies using Landsat data. Analogous phenomena might exist in other uranium-rich areas of the world (such as the Thelon Basin in the Northwest Territories and the Alligator River area of the Northern Territory, Australia) warranting similar Landsat analysis of data.

Acknowledgements

We thank DIPIX Systems Limited for use of their Ottawa facilities, Urangesellschaft Canada Ltd. for financing the remote sensing aspect and the Saskatchewan Department of Energy & Mines for support of field and analytical costs. The field component comprised part of a co-sponsored study by the Geological Survey of Canada and the Saskatchewan Geological Survey, conducted under the auspices of the International Atomic Energy Agency and the Nuclear Energy Agency.

We also thank J.D. Mollard of J.D. Mollard and Associates, Regina for assisting in the review of the paper.

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Uranium and Gold Geochemical Signatures, Athabasca Basin, Waddy Lake and Flin Flon Areas

by Michel Mellinger[1]

Mellinger, Michel (1985): Uranium and gold geochemical signatures, Athabasca Basin, Waddy Lake and Flin Flon areas; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Work in the Saskatchewan Research Council's Geochemistry and Data Analysis Project this year has focussed on the study of lithogeochemical signatures associated with uranium deposition in the Athabasca Basin and gold mineralization in the Waddy Lake and Flin Flon areas.

Uranium Signatures

A comparative study of major oxide and trace element signatures associated with uranium deposition and host rock alteration in unconformity-type uranium deposits of the Athabasca Basin was carried out in co-operation with the SRC's Mineral Deposits Project (Mellinger et al., 1985). The study is based on lithogeochemical data from drill core collected by the SRC during the past six years from several properties within the Athabasca Basin: Midwest Lake (main, north and south zones), Dawn Lake, Key Lake, Collins Bay, and Maurice Bay (Fig. 1). The samples include mainly altered and unaltered sediments of the Athabasca Group, as well as some hydrothermally altered basement rocks from drillholes on sections crossing major mineralization. Background data for the Athabasca Group were obtained from the regional drill holes remote from known uranium occurrences used by Ramaekers (1980) for lithostratigraphic correlation studies.

The samples were analyzed for 12 major oxides and 15 trace elements. Major oxide variation patterns were studied using correspondence analysis (Benzecri et al., 1980; Lebart et al., 1984) and interpreted in terms of mineralogical alteration trends. For each of these trends, trace and ore element associations were investigated using tails analysis (Mellinger, 1983, 1984a) and correspondence analysis of the element co-occurrence data.

The study shows that clay mineralogy is the best indicator of hydrothermal alteration in the diagenetic-hydrothermal environment in which these deposits formed, and that the alteration is accompanied by extensive quartz dissolution. *Illitization* is present everywhere and *chloritization* is very common, although less widespread in the altered rocks. The buffering capacity of the alteration fluid in terms of Mg^{2+} species (which is probably related to the nature of the interaction between fluid and basement rocks) and/or the temperature evolution of the fluid are probable controlling factors for the stability of chlorite. *Siderite precipitation* is also common but quite variable in extent from one location to another.

[1]Resources Sector, Saskatchewan Research Council, Saskatoon.

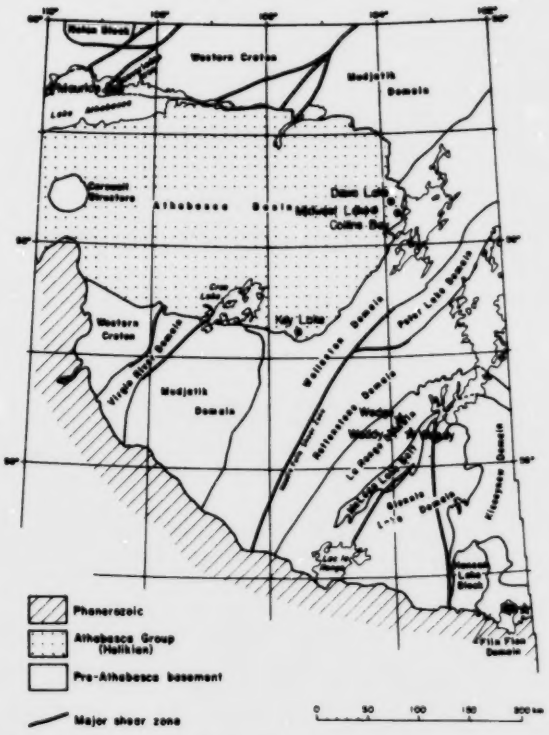

Figure 1 *- Location of study areas.*

Later clay mineral alteration also occurs in the form of extensive *chlorite overprinting* at Maurice Bay. At Key Lake the *'kaolinite halo'* above the Deilmann deposit has a bulk mineralogical composition similar to the background composition of the Manitou Falls Formation, except for the presence of rare quartz dissolution and related clay enrichment. The sandstone in the halo was either unaffected by hydrothermal alteration, or its clay mineral assemblage may have been at equilibrium with the circulating fluids at the time of uranium mineralization.

Trace and ore element signatures shed further light on the mineralization processes. Boron related to the presence of brines and strontium precipitated in phosphates are generally indicative of the *diagenetic-hydrothermal environment* in which the alteration and mineralization processes were active.

Mineralization processes produced U, Ni, Co, As, Pb, Cu, Zn, Mo and V, the first five elements being the most abundant. Although the precipitation of uranium as pitchblende and Ni-Co as arsenides or sulpho-arsenides is not coincident, the minerals are generally associated;

vanadium appears to generally follow Ni and Co, and Pb is usually not associated with U, due either to remobilization or a distinct galena mineralization event. A distinct sulfide mineralization stage involves Cu and/or Zn.

Later selective remobilization of the ore elements U, Co and Pb is apparent at Key Lake, where these elements were segregated in the 'kaolinite halo' located above the Deilmann deposit.

Gold Signatures

Following the sampling of the Weedy Lake, Waddy Lake and Wedge Lake properties in the La Ronge Belt and the Rio Mine in the Flin Flon area (Fig. 1) (Mellinger, 1984), selected samples were analyzed for a broad suite of major oxides and trace elements, and a preliminary study of the data was completed (Mellinger, 1985).

The B zone of the **Weedy Lake** property is contained within a variably sheared quartz diorite body (Coombe, 1984). The gold occurs in quartzofeldspathic rocks in the core of the quartz diorite, and has been deposited in conjunction with strong pyritization of the host rocks. A marked depletion of CaO and MgO noticeable in the ore zone may be related to the leaching out of hornblende and biotite. FeO and vanadium are also depleted in the ore zone, but both are strongly enriched immediately adjacent to the ore zone in the footwall. This peculiar signature is interpreted as resulting from the movement of the mineralizing fluids, possibly away from the neighbouring Byers Fault on the hangingwall side of the B Zone, with sequential (re)precipitation of elements due to physicochemical gradients of a yet unknown nature.

The **Komis zone** of the Waddy Lake property occurs in a metavolcanic sequence consisting mainly of basalt and some rhyolite which has been intruded by the Round Lake Pluton (Coombe, 1984). A distinct potassic alteration as well as pyritization are observed in the basalts hosting the gold mineralization. A vanadium signature similar to that observed in the B zone at Weedy Lake can be seen in one drillhole; vanadium enrichment occurs adjacent to a consistently mineralized section on the side farthest from the Round Lake Pluton. Also, geochemical evidence can be found which supports the hypothesis (Asbury and Zimmerman, oral presentation, 1985) that the iron necessary for pyrite formation may have been derived from the silicate minerals of the host rocks.

Only a limited suite of samples from **Wedge Lake** was analyzed geochemically. The gold mineralization occurs in pyrrhotite-rich iron formation. The gold is accompanied by Cu, Zn, Pb and Ni. Silicate-rich rocks adjacent to the iron formation are relatively poor in these elements but are strongly enriched in Mn. These observations are consistent with the volcanogenic exhalative origin for the Wedge Lake deposit put forward by Netolitzky (1985).

At the **Rio mine**, the main alteration in the host rocks is a very extensive carbonatization. Silicification (Pearson, 1984; Mellinger, 1984b) in the host-rocks is insignificant and is expressed only as minor quartz veins. As samples have only so far been studied from the ore zone, no further conclusions will be drawn at this time. A more complete study, including samples of the country rocks, is in progress.

In conclusion, this preliminary study shows that lithogeochemical signatures are associated with gold mineralization in these deposits and that they will provide information crucial to the understanding of gold deposition.

Acknowledgements

The study of uranium deposits was conducted in collaboration with Jan Hoeve and David Quirt. Sampling was carried out by V.J. Sopuck and K. Rawsthorn, in addition to the authors. Canada Wide Mines Ltd., Asamera Inc., Key Lake Mining Corp., Gulf Minerals Ltd. and Uranerz Exploration and Mining Ltd. are gratefully acknowledged for authorizing access to the properties sampled and for providing the background information necessary for planning the sampling program.

The author wishes to thank Golden Rule Resources Ltd., Waddy Lake Resources Inc., Giant Yellowknife Mines Ltd., Placer Development Limited, Peat Marwick Ltd. and SMDC for giving him authorization to present the preliminary results of the gold mineralization study.

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Lithogeochemistry of the Athabasca Group: Summary of Sandstone Data

by D.H. Quirt[1]

Quirt, D.H. (1985): Lithogeochemistry of the Athabasca Group: summary of sandstone data; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The program to study the lithogeochemistry of the Athabasca Group clastic rocks was conceived several years ago (Quirt, 1983) and has progressed slowly through the sample collection, preparation and analysis stages, data organization and interpretation stages. The objectives of the program are:

1) to compile and interpret background elemental concentrations and interelement correlations for the various formations of the Athabasca clastic sediments (sandstone-siltstone, clay-silt seams and clay pebbles);

2) to investigate regional variations within the formations;

3) to compare elemental concentrations and correlations for background areas with those for an area considered to be favourable for the formation of unconformity-type uranium deposits; and

4) to compare the existing lithostratigraphic boundaries with respect to lithogeochemistry.

This report is concerned only with the first of these objectives, dealing with the sandstone components of the Athabasca Group.

In the data summary that follows, the collected samples have been placed into the lithostratigraphic/clay mineral stratigraphic formations as discussed in Hoeve et al. (1981, 1983, 1985), Hoeve and Quirt (1985), Ramaekers (1979, 1980, 1981) and Wilson (1985). The formations, and the abbreviations used in the tables (bracketted), are: Locker Lake (LL), Upper Wolverine Point (WPb), Lower Wolverine Point (WPa), Lazenby Lake (LzL), Upper Manitou Falls (MFcd), Lower Manitou Falls (MFab), Upper Fair Point (FPb) and Lower Fair Point (FPa). At present, the remaining formations of the Athabasca Group have either for convenience been included in the Locker Lake Formation (Otherside) or have not been sampled adequately for interpretation (Tuma Lake, Douglas and Carswell). The column in Tables 1, 2, and 3 labelled 'Athabasca' contains weighted averages for the sample population.

Table 1 - Arithmetic Means, Major Element Oxides

	FORMATION[4]								
Oxide[5]	LL	WFb	WFa	LzL	MF c+d	MF a+b	FFb	FFa	Athabasca
Al_2O_3	1.16 ± 0.28	6.44 ± 1.13	4.43 ± 1.92	0.79 ± 0.11	1.92 ± 0.62	2.66 ± 0.42	6.83 ± 0.86	6.69 ± 0.96	3.65
TiO_2	0.06 ± 0.03	0.11 ± 0.02	0.12 ± 0.06	0.03 ± 0.003	0.09 ± 0.02	0.11 ± 0.03	0.11 ± 0.02	0.16 ± 0.03	0.10
K_2O	0.10 ± 0.02	0.95 ± 0.27	0.23 ± 0.10	0.08 ± 0.01	0.13 ± 0.02	0.09 ± 0.02	0.06 ± 0.01	0.21 ± 0.08	0.26
Na_2O	0.09 ± 0.01	0.15 ± 0.03	0.11 ± 0.02	0.13 ± 0.04	0.12 ± 0.02	0.13 ± 0.02	0.12 ± 0.01	0.14 ± 0.03	0.13
MgO	0.05 ± 0.01	1.27 ± 0.23	0.05 ± 0.03	0.03 ± 0.01	0.03 ± 0.005	0.03 ± 0.01	0.02 ± 0.003	0.05 ± 0.02	0.24
CaO	0.04 ± 0.01	0.22 ± 0.22	0.02 ± 0.02	0.03 ± 0.01	0.03 ± 0.02	0.01 ± 0.002	0.05 ± 0.03	0.08 ± 0.05	0.06
FeO	0.81 ± 0.22	0.42 ± 0.03	0.45 ± 0.04	0.58 ± 0.07	0.54 ± 0.04	0.49 ± 0.03	0.34 ± 0.03	0.35 ± 0.05	0.50
Fe_2O_3 calc[1]	0.27 ± 0.24	0.74 ± 0.17	0.46 ± 0.20	0.63 ± 0.53	0.78 ± 0.33	0.71 ± 0.36	1.37 ± 0.35	1.95 ± 0.52	0.78
P_2O_5	0.03 ± 0.01	0.04 ± 0.02	0.05 ± 0.02	0.03 ± 0.01	0.03 ± 0.01	0.04 ± 0.006	0.07 ± 0.01	0.09 ± 0.04	0.04
CO_2	0.43 ± 0.14	0.35 ± 0.13	0.28 ± 0.04	0.29 ± 0.06	0.30 ± 0.04	0.36 ± 0.04	0.21 ± 0.02	0.27 ± 0.05	0.32
LOI	0.47 ± 0.16	2.22 ± 0.43	1.25 ± 0.63	0.18 ± 0.05	0.59 ± 0.21	0.69 ± 0.14	2.47 ± 0.43	2.30 ± 0.33	1.19
H_2O[2]	0.17 ± 0.12	1.89 ± 0.41	0.98 ± 0.62	0.04 ± 0.03	0.37 ± 0.20	0.49 ± 0.13	2.27 ± 0.42	2.04 ± 0.33	0.93
SiO_2[3]	96.76 ± 0.67	87.30 ± 2.12	92.78 ± 2.78	97.33 ± 0.54	95.59 ± 0.92	94.83 ± 0.70	88.42 ± 1.26	87.83 ± 1.56	92.90
n	50	80	58	48	75	95	35	35	476

(1) Fe_2O_3 calc = Fe_2O_3 total - 1.1113 FeO

(2) by difference from LOI and CO_2

(3) by difference

(4) see text for explanation of formation abbreviations

(5) arithmetic mean ± 95% confidence interval (%)

[1]Resources Sector, Saskatchewan Research Council, Saskatoon.

Table 2 - Arithmetic Means, Trace Elements

Element[2]	FORMATION[1] LL	WPb	WPa	LzL	MF c+d	MF a+b	FPb	FPa	Athabasca
Mn	23.4 ± 4.5	45.7 ± 18.6	25.0 ± 4.7	30.8 ± 5.1	39.3 ± 14.9	32.2 ± 9.0	69.3 ± 17.5	67.3 ± 41.2	39.0
Cu	6.7 ± 1.0	5.1 ± 0.6	5.7 ± 1.1	4.3 ± 0.9	6.3 ± 0.7	10.0 ± 2.8	3.3 ± 0.5	4.5 ± 0.5	6.3
Zn	6.9 ± 2.1	7.3 ± 1.3	5.3 ± 1.7	4.9 ± 1.0	4.7 ± 0.8	13.8 ± 5.5	4.2 ± 0.6	8.2 ± 3.0	7.5
Pb	3.6 ± 0.7	3.2 ± 0.4	4.9 ± 1.0	3.5 ± 0.4	3.6 ± 0.6	3.7 ± 0.8	3.3 ± 0.9	3.5 ± 1.1	3.7
Ni	9.1 ± 0.9	10.2 ± 1.0	9.3 ± 0.7	10.6 ± 1.3	13.5 ± 1.2	9.9 ± 0.7	7.5 ± 0.8	12.1 ± 1.2	10.1
Cr[3]	402.0 ± 29.9	278.2 ± 37.2	372.2 ± 39.6	412.4 ± 33.2	488.2 ± 45.5	404.6 ± 30.7	317.7 ± 21.2	330.2 ± 29.1	321.2
Li	16.9 ± 9.6	51.4 ± 7.6	60.2 ± 20.7	4.1 ± 1.6	25.2 ± 10.8	19.0 ± 4.9	41.4 ± 9.2	62.6 ± 12.7	33.6
Ba	23.5 ± 2.8	55.1 ± 10.1	36.3 ± 7.4	17.3 ± 2.3	16.9 ± 4.4	19.2 ± 4.1	37.8 ± 4.1	37.3 ± 6.3	29.9
Rb	2.4 ± 0.5	28.0 ± 8.0	6.0 ± 3.3	2.0 ± 0.3	3.2 ± 0.7	2.3 ± 0.6	1.9 ± 0.3	6.0 ± 2.1	7.4
Sr	104.9 ± 41.2	83.2 ± 11.5	225.7 ± 94.3	116.5 ± 34.4	172.9 ± 83.5	161.7 ± 27.5	235.5 ± 34.5	293.1 ± 81.9	163.0
V	6.9 ± 1.4	9.8 ± 1.3	7.9 ± 2.0	9.9 ± 7.5	10.9 ± 2.2	9.4 ± 2.2	12.4 ± 3.0	19.6 ± 4.5	10.3
Co	2.4 ± 0.4	2.4 ± 0.3	1.6 ± 0.4	1.8 ± 0.3	1.9 ± 0.4	2.0 ± 0.3	2.1 ± 0.4	2.0 ± 0.5	2.0
As	0.7 ± 0.2	1.1 ± 0.3	1.4 ± 0.3	1.3 ± 0.3	1.2 ± 0.3	1.8 ± 0.3	0.8 ± 0.2	1.1 ± 0.3	1.2
Ag	0.2 ± 0.03	0.2 ± 0.06	0.2 ± 0.06	0.2 ± 0.02	0.2 ± 0.08	0.2 ± 0.04	0.1 ± 0.02	0.2 ± 0.04	0.2
U	0.7 ± 0.2	2.6 ± 0.5	1.3 ± 0.4	0.9 ± 0.3	1.8 ± 0.5	1.1 ± 0.1	1.2 ± 0.2	1.9 ± 0.6	1.5
Mo	7.8 ± 1.1	6.5 ± 0.5	6.4 ± 0.7	5.3 ± 0.3	6.4 ± 0.6	5.4 ± 0.2	6.4 ± 0.7	6.1 ± 0.8	6.2
B	25.4 ± 5.6	160.3 ± 43.5	44.5 ± 16.6	17.3 ± 2.8	21.5 ± 5.6	13.9 ± 1.8	29.4 ± 4.7	38.3 ± 6.2	47.9
Th	3.8 ± 0.6	7.4 ± 1.1	7.5 ± 2.2	4.0 ± 0.4	7.3 ± 1.0	18.2 ± 5.6	14.1 ± 2.5	14.5 ± 4.1	9.8
Y	5.1 ± 1.5	22.2 ± 4.5	11.1 ± 4.6	3.5 ± 0.6	4.3 ± 0.8	3.4 ± 0.6	4.6 ± 0.7	5.9 ± 1.2	8.1
Zr	97.3 ± 52.1	155.9 ± 21.5	201.2 ±103.4	74.0 ± 13.2	200.8 ± 42.8	176.7 ± 32.8	88.4 ± 8.4	122.7 ± 24.4	150.8
Cd	1.4 ± 0.3	1.3 ± 0.2	1.4 ± 0.2	1.7 ± 0.5	1.5 ± 0.2	1.2 ± 0.1	1.2 ± 0.2	1.5 ± 0.3	1.4
Au[4]	4.9 ± 1.4	8.9 ± 1.4	10.6 ± 1.5	5.1 ± 1.3	11.2 ± 0.8	10.1 ± 0.2	10.3 ± 1.3	10.6 ± 0.8	9.2
Be	1.2 ± 0.2	1.5 ± 0.2	1.0 ± 0.1	1.0 ± 0.06	1.0 ± 0.06	1.0 ± 0.09	1.0 ± 0.1	1.0 ± 0.1	1.1
La	14.0 ± 1.6	38.0 ± 3.6	22.9 ± 4.5	12.0 ± 2.3	11.1 ± 2.8	18.2 ± 2.9	22.6 ± 2.9	27.2 ± 9.4	20.9
n	50	80	58	48	75	95	35	35	476

(1) see text for explanation of formation abbreviations

(2) arithmetic mean ± 95% confidence interval (ppm)

(3) Cr values strongly affected by grinding contamination

(4) Au values in ppb

During sample preparation, grinding of the samples (to -250 mesh) was carried out using a steel mill which, although efficient, introduced contaminants into the samples. Table 5 lists the results of two analyses of clear euhedral quartz crystals prepared using a motorized agate mortar on the one hand and the steel mill on the other. For the elements analysed, only iron (0.02 percent vs. 0.79 percent) and chromium (12 ppm vs 916 ppm) show significant contamination from the steel. Because of this, the listed values for chromium have not been used in the subsequent data treatment and the iron values have been used only in a qualitative manner. Re-analysis of the samples for these elements, after grinding with the agate mortar, is now in progress. Sample data that returned from analysis as null values were given a value equal to half the applicable elemental detection limit (Table 4), while data with values of less than the detection limit were set to that value.

The major element patterns can be described briefly in terms of four factors: (1) the type (kaolinite, illite, chlorite) and amount of clays, (2) the oxidation state of iron, (3) the presence/absence of heavy minerals and (4) the origin and maturity of the sediments. As the Athabasca sandstones are relatively rich in quartz (Fig. 1), the first and last of these factors are the most important to this discussion.

In general, the quartz/clay ratio determines the gross major element distribution, as most of these elements are bound to the clays either structurally or in interlayer locations. The Athabasca clay species, consisting of kaolinite and illite in varying proportions with or without di-, tri-chlorite, was determined by the availability of K^+ and Mg^{2+} with respect to the amount of clay present. Except for the Upper Wolverine Point Formation, the dominant detrital clay is kaolinite (a hydrous aluminosilicate lacking other cations) which will convert into illite or chlorite (K- and Mg-hydrous aluminosilicates respectively) if the cations are available and the physicochemical conditions are satisified. This also applies to the formation of diagenetic clays. The Upper Wolverine Point Formation, being of marine origin, in distinction to the other continental units, was likely a smectite-illite-chlorite assemblage which has been

Table 3 - Geometric Means, Trace Elements

Element[2]	Formation[1] LL	WPb	WPa	LzL	MFc+d	MFa+b	FPb	FPa
Mn	20.5	29.3	21.1	26.1	25.6	24.9	52.7	39.2
Cu	5.9	4.3	4.5	3.2	5.6	7.0	3.0	4.2
Zn	4.8	5.5	3.2	3.9	3.7	7.0	3.8	6.9
Pb	2.9	2.7	3.7	3.1	3.0	2.8	2.6	2.5
Ni	8.6	9.6	9.0	9.9	12.5	9.3	7.0	11.6
Cr[3]	392.8	217.0	337.0	332.5	450.6	377.4	312.7	320.5
Li	6.5	37.9	27.5	2.4	12.0	12.4	31.9	50.6
Ba	21.9	45.0	30.9	15.8	14.1	15.5	35.3	33.2
Rb	1.9	12.9	2.8	1.8	2.5	1.8	1.7	3.4
Sr	72.0	73.4	134.1	93.9	100.1	125.8	205.8	233.3
V	5.4	8.1	6.1	5.6	8.5	6.4	9.2	13.5
Co	2.0	1.9	1.3	1.6	1.5	1.6	1.8	1.6
As	0.5	0.8	1.1	1.0	0.9	1.3	0.7	0.8
Ag	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.1
U	0.5	1.8	0.9	0.7	1.1	0.9	1.1	1.4
Mo	7.1	6.2	6.1	5.2	6.0	5.3	6.2	5.8
B	20.0	84.1	26.8	15.3	16.5	12.5	26.3	33.6
Th	3.5	6.0	5.1	3.8	6.2	10.1	12.3	11.3
Y	3.5	17.3	6.1	3.0	3.3	2.5	4.2	4.9
Zr	67.3	128.1	113.5	64.3	148.8	131.5	85.8	109.5
Cd	1.2	1.1	1.2	1.3	1.3	1.1	1.1	1.4
Au[4]	2.4	5.1	8.3	2.1	10.9	10.1	9.3	10.4
Be	1.1	1.3	1.0	0.9	0.9	1.0	1.0	1.0
La	13.1	34.8	18.4	10.4	9.0	14.3	21.0	20.4
n	50	80	58	48	75	95	35	35

(1) See text for explanation of formation abbreviations.
(2) geometric mean (ppm)
(3) Cr values strongly affected by grinding contamination.
(4) Au values in ppb

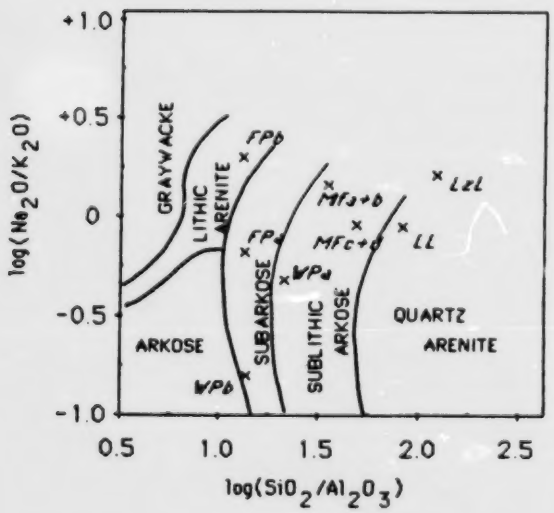

***Figure 1** - Chemical composition of Athabasca Group sandstones.*

Table 4 - Analytical Detection Limits and Methods of Analysis

element	detection limit	method(1)	element/oxide	detection limit	method(1)
Li	1.0 ppm	ICP	Al_2O_3	0.1 %	AAS
U	0.2	FLR	Fe_2O_3	0.01	AAS
Rb	1.0	AAS	TiO_2	0.01	ICP
B	10.0	ICP	CaO	0.01	AES
Ag	0.1	AAS	MgO	0.01	AES
Au	0.3 ppb	AAS	K_2O	0.02	AES
As	0.2 ppm	AAS	Na_2O	0.02	AES
Mo	5.0	ICP	MnO	0.001	ICP
Zn	1.0	ICP	P_2O_5	0.01	ICP
Cd	1.0	ICP	FeO	0.1	TIT
Co	1.0	ICP	CO_2	0.2	LIF
Cr	1.0	ICP	LOI	0.1	LIF
V	1.0	ICP	Th	3.0 ppm	ICP
Be	1.0	ICP	Sr	1.0	ICP
Cu	1.0	ICP	Ba	1.0	ICP
Zr	1.0	ICP	Ni	2.0	AAS
Y	1.0	ICP	Pb	2.0	AAS
La	1.0	ICP			

(1) methods AAS - Atomic Absorption Spectrophotometry
AES - Atomic Emission Spectrometry
ICP - Inductively Coupled Plasma emission spectrometry
TIT - Titration
FLR - Fluorimetry
LIF - Leco Induction Furnace

converted, through diagenesis, to illite-chlorite. This is also true to some extent of the Lower Wolverine Point Formation, as it is a transitional unit between continental and marine formations. The coherent lateral and vertical variations in the proportions of clay minerals in these sediments corresponds well to the lithostratigraphy and lithogeochemistry.

The chemical classification of these sandstones (Fig. 1) using silica, alumina and alkali values (Pettijohn et al., 1972) is not too useful for naming purposes but is relevant to discussions of the relationships between elemental composition, mineralogy and rock type. The silica/alumina ratio is a measure of the mineralogical maturity (total clay content) of the sediment while the Na_2O/K_2O ratio reflects the proportion of illite with respect to kaolinite.

The SiO_2/Al_2O_3 ratios show that only the Locker Lake and Lazenby Lake Formations can be classified as quartz arenities, while the more clay-rich formations fall into the sublithic arkose (Lower Wolverine Point and Fair Point Formations), subarkose (Lower Fair Point and Upper Wolverine Point Formations) and lithic arenite (Upper Fair Point Formation) classifications, while the Na_2O/K_2O

Table 5 - Comparison of Sample Milling Techniques

element/oxide	agate mortar	steel mill	element	agate mortar	steel mill
Al_2O_3	0.80 %	0.90 %	Co	1 ppm	2 ppm
Fe_2O_3	0.02	0.79	Cr	12	916
TiO_2	0.01	0.01	V	7	7
CaO	0.02	0.03	Be	1	1
MgO	0.01	0.01	Cu	2	4
K_2O	0.01	0.01	Zr	11	12
Na_2O	0.01	0.01	Y	1	2
MnO	0.001	0.003	La	2	2
P_2O_5	0.01	0.01	Th	2	3
Mo	5 ppm	7 ppm	Sr	2	4
Zn	1	2	Be	1	2
Cd	1	1			

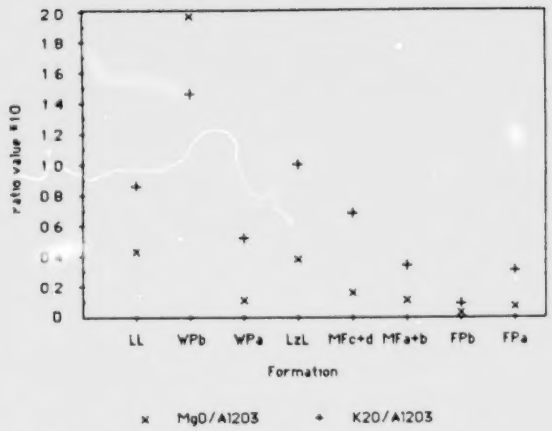

Figure 2 *- Potassium and magnesium versus aluminum ratios.*

ratios show no great variation, the marine unit (WPb) and the transitional continental-marine unit (WPa) follow a trend to increased potassium, indicating a dominance of illite over kaolinite. This trend is very evident when the ratios of magnesium and potassium versus alumina are plotted (Fig. 2), where high in magnesium (chlorite) and potassium (illite) shows up for the Upper Wolverine Point. This association parallels the elevated alumina, water and LOI values, indicating an increased clay content.

In the Athabasca sediments, the presence of heavy minerals is not common except as hematite cement. Rare detrital grains of tourmaline, hematite and zircon are found, while heavy mineral bands (HMB) are encountered in varying numbers. The paucity of heavy minerals is reflected in the relatively low values for all elements except alumina and silica. The ratio of iron species ($FeO/(FeOFe_2O_3)$), indicating the present oxidation state, varies considerably, even within formations. The ratios for most units, however, are consistently around 0.35 to 0.45. Thin section analysis indicates that hematite (Fe^{3+}) is common, as are clays (Fe^{2+}). The Locker Lake and Fair Point Formations differ from the above as well as from each other. Both the Upper and Lower Fair Point Formations give ratios of less than 0.20, due to a relatively high hematitie content in these rocks. The Locker Lake Formation, on the other hand, shows a typical ratio greater than 0.70, corresponding to somewhat elevated CO_2 values (and thin section findings of intergranular siderite) for samples from this formation. Dilution of the CO_2 mean value is possible due to the inclusion of samples from the Otherside Formation.

The major element geochemistry of the Athabasca Group samples, when broken down into litho- and clay stratigraphic formations, can be summarized as follows:

Fair Point Formation:
- clay rich (high Al_2O_3, LOI, H_2O)
- oxidized, hematitic (low iron ratio)
- Lower Fair Point more illitic than Upper (K_2O, Fig. 2)

Manitou Falls Formation:
- Upper Manitou Falls more illitic but less clay-rich than the Lower Manitou Falls (K_2O, Al_2O_3, H_2O, LOI, Fig. 2)
- Lower Manitou Falls relatively rich in HM (TiO_2 with respect to Al_2O_3)

Lazenby Lake Formation:
- very low clay content, few HM, very clean sandstone (low Al_2O_3, TiO_2, Fig. 1)
- illitic (K_2O, Fig. 2)

Wolverine Point Formation:
- Lower Wolverine Point is intermediate, transitional to Upper Wolverine Point from Lazenby Lake and Manitou Falls (Al_2O_3, K_2O, LOI, Fig. 1)
- Lower Wolverine Point clay-rich (Al_2O_3, K_2O, LOI), chloritic (MgO) and illitic (K_2O)

Locker Lake Formation:
- low clay content (Al_2O_3, LOI, H_2O, TiO_2, Fig. 1)
- illitic (K_2O, Fig. 2)
- reduced, sideritic (high iron ratio, CO_2)

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Geology and Genesis of the Athabasca Basin Uranium Deposits

by T.I.I. Sibbald

Sibbald, T.I.I. (1985): Geology and genesis of the Athabasca Basin uranium deposits; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

Pitchblende was first discovered in Saskatchewan in 1935 at the Nicholson copper prospect on the north shore of Lake Athabasca (Fig. 1). Note of this occurrence was made in Alcock's (1) Geological Survey of Canada Memoir "The Geology of the Lake Athabasca Region".

Recognition of the military significance of uranium in the early forties led to an extensive uranium exploration effort by the Government of Canada through Eldorado, a Crown Corporation. This effort began at Nicholson, then one of three known occurrences of radioactive minerals in Canada. The others were Eldorado's, Port Radium, radium mine on Great Bear Lake, which was now being mined for uranium, and an unsubstantiated occurrence on the north shore of Lake Superior which would subsequently lead to Elliot Lake.

In the 1945 field season, in what eventually became known as the Beaverlodge District, prospecting found over 1000 radioactive showings. In the following year the occurrences which would become Eldorado's Ace-Fay-Verna operation were discovered. Uranium production from Beaverlodge amounted to some 25 million kg U between 1953 and 1982, when Eldorado finally shut down. Over the years there was production from 17 main deposits and milling at 3 separate facilities (Table I, Fig. 1).

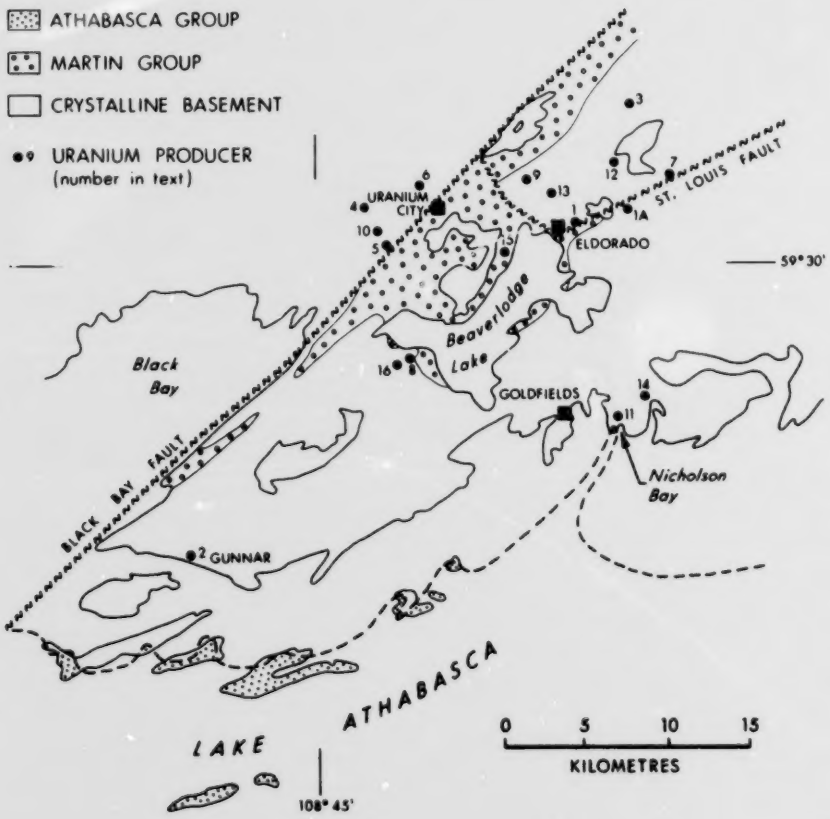

***Figure 1** - Major uranium producers of the Beaverlodge District in relation to the outcrop of the Martin and Athabasca Groups. Numbers refer to Table I.*

Table I - Major Uranium Producers, Beaverlodge District

	Uranium Mine	Production (t U)
1.	Eldorado, Ace-Fay-Verna (1A)	16 035
2.	Gunnar	6 892
3.	Eldorado, Hab	763
4.	Rix Smitty	436
5.	Cinch Lake	285
6.	Cayzor Athabasca	187
7.	Eldorado, Dubyna	163
8.	Lorado	89
9.	Eldorado, Eagle	85
10.	Rix Leonard	77
11.	Nicholson	41
12.	National Exploration	30
13.	Nesbitt Labine	23
14.	Eldorado, Fish-hook	15
15.	Eldorado, Martin Lake	11
16.	Uranium Ridge	10
		25 142

Exploration in the Athabasa Basin began in 1967, encouraged by the Government of Saskatchewan through a financial assistance program to companies with approved exploration work schedules. In 1968, following up airborne radiometric anomalies along the eastern edge of the Basin, the Gulf Oil Company discovered Rabbit Lake (Table II, Fig. 2). An exploration philosophy designed to find sandstone hosted deposits in the Athabasca Group identified an orebody in the underlying crystalline basement.

Also at this time, Mokta (Canada) Ltd. a subsidiary of Compagnie de Mokta that had been exploring in Saskatchewan since 1963, sent a team to investigate certain airborne radiometric anomalies in the Carswell Dome area. Initially attracted to Beaverlodge, the company was soon to turn its attention to the Athabasca Basin, undoubtedly prompted by experience with sandstone hosted uranium deposits in Gabon and the discovery, in 1967, of mineralized boulders of Athabasca Group sandstones at Fond-du-Lac. In 1969, ground trenching of the Carswell anomalies led to the discovery of pitchblende boulders in glacial overburden and thence to the D zone orebody, which was of extremely high grade (6 percent U).

The next significant find was at Key Lake, first the Gaertner orebody in 1975 and the Deilmann in 1976. The initial clue, which attracted Uranerz Exploration and Mining Ltd. geologists to the area, was a uranium in lake water anomaly identified in a previous exploration effort, in 1969, but not further pursued. On visiting the anomaly area in late 1971, high grade pitchblende boulders, now known to be derived by fluvioglacial erosion from the Gaertner orebody, were found within a matter of hours.

At the time of the Key Lake discovery the Saskatchewan Geological Survey, financed under a Canada-Saskatchewan mineral exploration and development agreement was engaged in a major mapping program in the Shield. In the 1976 field season work in the Key Lake area was instrumental in demonstrating the association between the deposits, graphitic pelitic gneisses forming the basal unit of the Aphebian Wollaston Group, and the sub-Athabasca Group unconformity. It became quickly apparent that a little known deposit, the Collins Bay A zone discovered by Gulf in 1971, occupied a geologically similar position. The role of 'graphitic basement units', recognizable as electromagnetic conductors, in controlling the locations of unconformity type uranium deposits became established as an idea.

Application of this idea led to re-evaluation of the Collins Bay A zone (1976), and discovery of the West Bear deposit (1977) and Collins Bay B zone (1977) by Gulf. Imperial Oil Ltd. (Esso Minerals Canada Ltd.) and joint venture partners had cause to review the significance of a mineralized boulder train found by prospectors in 1969 at Midwest Lake. The Athabasca Group boulders comprising the train overlay a possible basement conductive zone covered by Athabasca Group sediments estimated to be up to 300 m thick. Deep drilling in 1977 showed low grade mineralization at the Athabasca Group-basement unconformity and in 1978 an economic orebody was delimited.

The Midwest discovery illustrated that the deeper parts of the Basin could be explored, previous successes being confined to the margins. Additionally, it led to general acceptance and implementation of the Key Lake exploration model. Several significant discoveries followed within the Basin at depths of up to 440 m, for example at Dawn Lake (1978), McClean Lake (1979) and more recently Cigar Lake (1981). These deposits lack a guiding surface expression of mineralization, as boulders, and were outlined by systematic drilling of electromagnetic conductors defined in airborne and ground follow up surveys.

The supreme irony is that recent work (2, 3) has shown that the first discovery of uranium in Saskatchewan, at Nicholson, was of an Athabasca Basin unconformity type deposit. It took 33 years to find the first economic deposit of this type, at Rabbit Lake, although minor occurrences were discovered at Middle Lake (1952), Stewart Island (1955) and Fond-du-Lac (1967) (Fig. 2), and nearly 50 years to appreciate the significance of Nicholson. In the interim, the wholly different Beaverlodge uranium district was discovered, developed and mined, establishing Saskatchewan as a world uranium producer.

The Athabasca Basin contains some 14 percent of the reasonably assumed low cost uranium resources of the free world and around 70 percent of Canadian resources. Most of the Athabasca Basin resources are contained within two major deposits at Key Lake and Cigar Lake. Grades of mineralization are often extremely high, as at the Collins Bay A zone (9.7 percent U), Cigar Lake (12 percent U) and the lately mined Cluff Lake D zone (6 percent U) (Table II).

Currently developed deposits, representing the earlier discoveries, are located at the margin of the Basin in open pits (Rabbit Lake, Cluff Lake D zone, Key Lake, Collins Bay B zone) or in shallow underground operations (Cluff, other). The more recent discoveries have been made under an increasing thickness of Athabasca Group cover (up to 440 m at Cigar Lake) and will require underground extraction.

General Geology of Northern Saskatchewan

The crystalline basement of northern Saskatchewan is part of the Trans-Hudson Orogen, which extends some 5000 km from Greenland to the mid-continental United States (4). It comprises Archean and Aphebian rocks variably influenced by Lower Proterozoic thermotectonic events (Fig. 3).

In northwestern Saskatchewan, around Uranium City, the crystalline basement is overlain by red beds of the late Aphebian Martin Group (Fig. 1). Further south the younger Paleohelikian Athabasca Group, also showing red bed character, forms the Athabasca Basin encompassing about one third of the Saskatchewan Shield area. The crystalline basement and overlying successions are cut by easterly and northwesterly

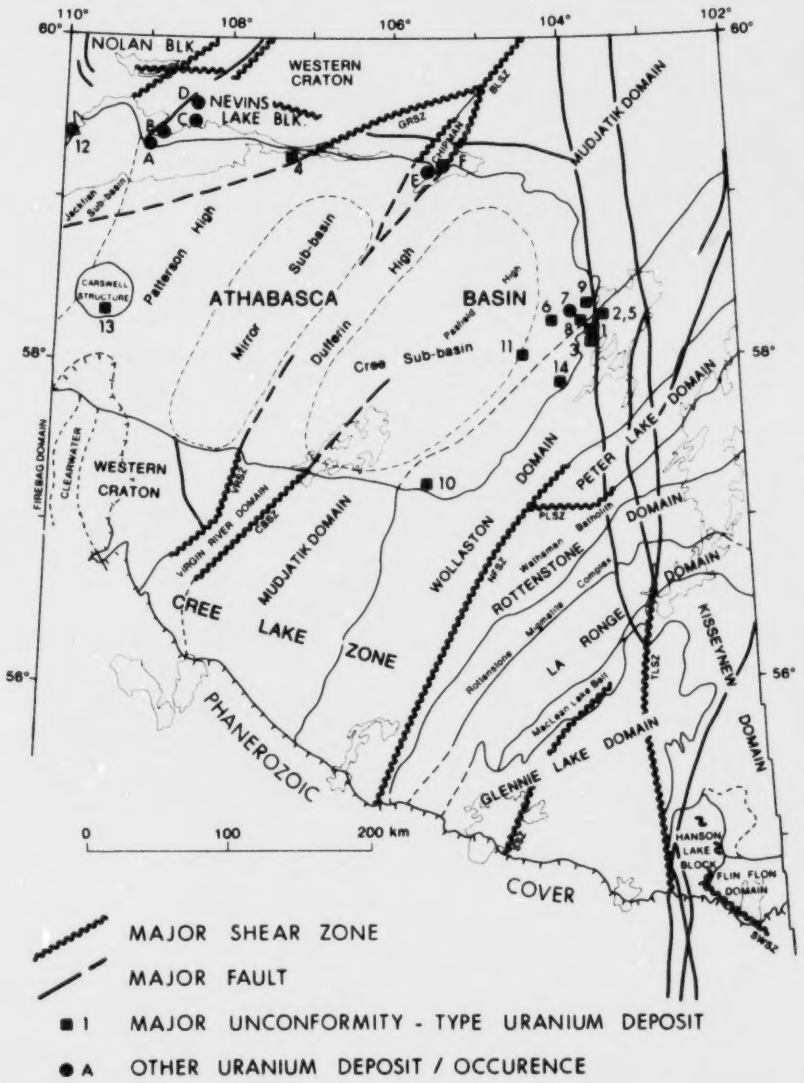

***Figure 2** - Major Athabasca Basin unconformity type uranium deposits and tectonic subdivisions of the Saskatchewan Shield. Numbers refer to Table II; other uranium deposits (A. Stewart Is., B. Gunnar, C. Nicholson, D. Ace-Fay-Verna, E. Middle Lake, F. Nisto). VRSZ-BLSZ, Virgin River-Black Lake Shear Zone, NFSZ. Needle Falls Shear Zone.*

Table II - Major Athabasca Basin Unconformity-Type Uranium Deposits

	Deposit	Ownership	Discovery date	Reserves tonnes U	Grade % U	Athabasca Gp. thickness (m)	Basement Rock Types	Depth of Mineralization (m)	Remarks
1	Rabbit Lake	Eldor Mines Limited	1968	15,400	0.4	Absent (eroded)	Meta-arkose, plagioclasite (in part graphitic), calcsilicate dolomitic marble, granite segregation pegmatite, microgranite	0-200	In hanging wall of Rabbit Lake thrust fault. Subcrop below drift. Mineralized boulder train. Mined out.
2A	Collins Bay A	"	1971	6,500	9.7	Absent (eroded)	Pelitic graphitic gneiss, granite segregation pegmatite in contact with granitoid gneiss	5-20	In clay zone at Athabasca Group unconformity in hanging wall of Coolins Bay thrust fault. Subcrop below drift. Mineralized boulder train.
2B	Collins Bay B	"	1977	11,900	0.4	25	Pelitic graphitic gneiss, granite segregation pegmatite in contact with granitoid gneiss	5-30	Dominantly in Athabasca Group in footwall of Collins Bay thrust fault. Subcrop below drift
2C	Collins Bay D	"	1979	1,900	1.6	-	Pelitic graphitic gneiss, granite segregation pegmatite	-	Adjacent to Collins Bay thrust fault
3	Raven	"	1972	-	0.2	Absent (eroded)	Sillimanite quartzite, calcareous meta-arkose, semipelitic gneiss	0-300	-
3A	Horseshoe	"	1974	-	0.2	Absent (eroded)	Sillimanite quartzite	60-300	-
4	Fond-du-Lac	Eldorado Nuclear Limited	1967	400	0.2	30	Meta-arkose, pelitic gneiss (occasionally graphitic)	10-30	Mineralization in Athabasca Group. Subcrop below drift. Mineralized boulder train
5A	Eagle Point South Zone	Eldor Mines Limited	1980	7,000	0.5	Absent (eroded)	Pelitic-semipelitic gneiss (in part graphitic), quartzite, granite segregation pegmatite	0-300	In hanging wall of Collins Bay thrust fault. Stratabound in quartzite and fracture fillings. Subcrop below drift.
5B	Eagle Point North Zone	Eldor Mines Limited - Noranda - SMDC	1980	15,000	1.6	Absent (eroded)	"	"	"
6	Midwest Lake	Esso Canada Ltd. - Numac Oil and Gas - Bow Valley Industries and others	1978	13,500	3.0	200	Pelitic graphitic gneiss locally with garnet, granite segregation pegmatite, bounded by granitoid gneiss;	0-300	Dominantly at sub-Athabasca Group unconformity, mineralization extends more than 100 m below unconform-

							crosscutting diabase dykes		ity and to surface (source of mineralized boulder train)
7	Dawn Lake (11, 11A, 11B and 14 zones)	SMDC - Cogema Canada - PNC and others	1978	11,500	1.7	100	Pelitic graphitic gneiss, calc-silicate, granite segregation pegmatite	30-200	Mineralization extends 50m above and 100m below the Sub-Athabasca Group unconformity. No surface expression.
8	McClean Lake (North and South Zones)	Canadian Occidental Petroleums - Inco Metals Ltd. - Minatco Ltd.	North 1979 South 1980	5,400	1.5	150	Pelitic graphitic gneiss granite segregation pegmatite	115-190	Mineralization extends above and below sub-Athabasca Group unconformity. No surface expression.
9	Jeb	"	1982	-	-	100	Pelitic graphitic gneiss	85-120	No surface expression
10	Key Lake	SMDC - Uranerz Exploration and Mining Limited - Eldor Resources Limited (Key Lake Mining Corp.)	1975	73,900	2.0	0-60	Graphitic pelitic gneiss adjacent to granitiod gneiss massif	50-150	Mineralization extends above and below sub-Athabasca Group unconformity but predominantly below within 20m of unconformity. Subcrop below drift. Mineralized fluvio-glacial boulder train
11	Waterbury (Cigar) Lake	SMDC - Cogema Canada - Idemitsu Uranium Exploration Canada Ltd. - Corona Grande (Cigar Lake Mining Corp.)	1981	110,000 (38,000 additional estimated)	12.0 (4)	440	Graphitic pelitic gneiss, minor calc-silicate, granite segregation pegmatite	± 440	Mineralization predominantly in lens at sub-Athabasca Group unconformity. Some fracture controlled mineralization above and below unconformity No surface expression
12	Maurice Bay	SMDC - Uranerz Exploration and Mining Ltd.	1977	600	0.5	0-130	Pelitic gneiss (in part graphitic), minor quartzite and amphibolite	0-150	Mineralization in three zones. Athabasca Group (B and Main) and basement (A). Subcrop below drift. Mineralized boulder train
13A	Cluff Lake D	Amok Ltd. - SMDC (Cluff Mining)	1969	5,400 (3,300 production)	6.0	-	Pelitic to semipelitic gneiss (in part graphitic) (Peter River Gneiss)	0-35	Mineralization in Athabasca Group sandstones and siltstones at thrust fault-inverted unconformity. Mineralized boulder train. Subcrop below drift. Mined out.
13B	Cluff Lake (other)	"	1969-1980	14,000	ca.0.5	-	Pelitic to semipelitic gneiss (in part graphitic (Peter River Gneiss) quartzofeldspathic gneiss (Earl River Gneiss), granite pegmatite	0-300	Fracture controlled mineralization in basement
14	Westbear	Eldor Mines Limited	1977	400	0.5	-	Pelitic graphitic gneiss	-	-

trending diabase dykes, probably emplaced in several generations.

Crystalline Basement

The basement comprises both ensialic and ensimatic portions of the Orogen, respectively developed to the west and east of the Needle Falls Shear Zone (5). The major change in crustal character, between early Aphebian continental-miogeoclinal and oceanic-eugeoclinal sedimentation regimes, has apparent continuity as a deep crustal conductivity anomaly below the Canadian plains (6) with a geologically similar break in Wyoming (7). The Athabasca Basin lies wholly within the ensialic portion of the Orogen formed by two major crustal elements, the Western Craton and the Cree Lake (Mobile) Zone. These two units are further subdivided into various lithostructural domains, or regimes of relative lithological, structural and metamorphic homogeneity (8).

The Western Craton: Bounded in the east by the Virgin River - Black Lake Shear Zone, the Western Craton incorporates the Firebag, Western Granulite and

***Figure 3** - General geology and major subdivisions of the Churchill Province in northern Saskatchewan (after Lewry and Sibbald, 5]).*

Clearwater Domains and the region north of Lake Athabasca (Figs. 2, 3). It extends into Northwest Territories as far as the Macdonald Fault and Thelon Front, marking the edge of the Archean Slave Province.

South of the Athabasca Basin, the Western Granulite Domain comprises felsic to mafic gneisses and granulites, charnockites, anorthosites, gabbros and minor supracrustals. Blue quartz is characteristic of the felsic rocks. Metamorphic mineral textures and parageneses indicate static pyroxene granulite facies metamorphism overprinted by a lower amphibolite facies event, whose effects are progressively more strongly developed towards the Virgin River Shear Zone (8). The Firebag Domain appears to have broadly similar character (9).

The Clearwater Domain truncates abruptly magnetic and presumed structural trends, and forms a zone of low magnetic signature and gravity within the high amplitude magnetic and high gravity granulite facies terrain of the Western Granulite and Firebag Domains. It is virtually unexposed, however, the limited outcrop and drill hole data suggest a granitoid gneiss terrain similar to that forming the bulk of the Mudjatik Domain, but of somewhat lower, middle to upper amphibolite facies metamorphic grade.

The mylonitized granulites at the southern end of the Virgin River Shear Zone are intruded by a late tectonic, uranium enriched (ca. 8 ppm U) granite (Junction Granite) (10), dated at 1720±45 Ma (11). A similar body, the Clearwater Granite, occurs at the contact of the Clearwater and Western Granulite domains and is possibly more extensive beneath the Phanerozoic cover rocks to the north (12).

The Western Granulite Domain and by analogy the Firebag Domain are interpreted (5, 8) as catazonal Archean crust, mildly overprinted by Hudsonian (sensu lato)[1] thermotectonic processes coeval with those in the Cree Lake Zone to the east. The Clearwater Domain may represent a region of more extensive reworking within the cratonic complex (5, 8), although others (13) have suggested that it represents an Aphebian structurally controlled sedimentary trough within the Archean basement. There are presently no age data to better evaluate the merit of these interpretations.

To the north of Lake Athabasa the Western Craton is geologically complex and comparatively poorly understood. It comprises distinct Archean elements and Aphebian supracrustal sequences, variously influenced by Hudsonian (sensu lato) thermotectonism. The Archean elements are identifiable, in part at least, as granulite facies terrains, for example, the Nolan Block north of Tazin Lake (14) and eastern segment of the Nevins Lake Block east of Uranium City (15, 16) (Fig. 2). These have been dated respectively at 2370±40 Ma (biotite and hornblende, K-Ar method) (14) and 2630±130 Ma (Rb-Sr isochron method) (17). Other, as yet undated, granulite facies 'nuclei' are apparent from mapping and are noted by Lewry et al. (18).

Hudsonian (sensu lato) thermotectonism is marked by retrogression in the granulite facies terrains and by development of 'linear zones' of more intense deformation and greenschist to upper amphibolite (granulite ?) facies metamorphism (19), in which an Archean prehistory is less evident (20, 21, 22) and in which Aphebian supracrustals are locally identified. The 'linear zones' exhibit a variety of character, occurring as granitoid migmatite complexes, as supracrustal complexes intruded by granite plutons and as shear zones marked by strong tectonism (mylonite development) and retrogression. Age dating by various methods suggests a complex history of orogenesis within these zones with events at around 2200 Ma (19, 22), 1850-2000 Ma (19, 21, 23, 24, 25, 26) and 1750 Ma (23, 27). The latest event of Hudsonian (sensu stricto) age marks the time of initial emplacement of epigenetic pitchblende mineralization at Beaverlodge and likely occurred subsequent to deposition of the Martin Group. However, it is coeval with more major orogenic events in the Trans-Hudson Orogen to the southeast (11), suggesting that Hudsonian (sensu lato) orogeny was diachronous and migrated with time from northwest to southeast.

On a broad scale, both the Clearwater Domain, Virgin River Shear Zone and the eastern segment of the Western Craton north of Lake Athabasca fall within a belt of regional low gravity and high radiometric signature stretching from the Western Cordillera to Melville Peninsula (28). The high radiometric response has been recognized through regional airborne radiometric surveys, conducted by the federal government, in the shield area and through chemical analysis of basement cores, from beneath the Phanerozoic cover of the central plains (29). Darnley (28) has argued that the belt may represent a regime of incipient rifting into which uranium rich granites were emplaced in Hudsonian (sensu stricto) times. The general association of negative gravity and these granites is well known. The belt is suggested to have played a multifacetted role in the development of the Athabasca Basin uranium province and others (Thelon and Southeast B.C. provinces), which fall along it. Continued rifting in post-Hudsonian times may have provided the depressions in which the Athabasca Group and Thelon Formation were laid down, and the radiogenic granites, a long term heat source to drive hydrothermal mineralizing systems within these sedimentary basins.

The Cree Lake (Mobile) Zone: This Hudsonian (sensu lato) mobile zone is represented by the Virgin River, Mudjatik and Wollaston Domains and their extensions northeast of the Athabasca Basin (Fig. 3). It comprises granitoid gneisses and subordinate shelf-type

[1]Hudsonian (sensu lato) refers to radiometric events within the time frame ca. 2200 to 1750 Ma, Hudsonian (sensu stricto) to the ca. 1750 Ma event.

metasediments with some interlayered volcanics. The supracrustals are most extensively developed in the Wollaston Domain as the Wollaston Group (30), a three to four kilometre thick sequence (31). Four main lithostratigraphic units are distinguished (5) (Fig. 4):

1) A coarse clastic basal unit, of variable thickness, developed principally along the eastern margin of the Cree Lake Zone and comprising mature quartzitic to arkosic metasediments, locally developed basal conglomerate and semipelitic to pelitic muscovite and biotite schists. Locally it may itself be underlain, possibly unconformably, by a sequence of immature meta arkoses, arkosic metaconglomerates and interbedded basic meta-volcanics. To the west it is generally not identified or is seen only as a thin basal quartzite.

2) A dominantly pelitic unit, which is typically graphitic and contains interlayers of quartzitic psammites, calc-silicates and occasionally marble. The unit rests directly on Archean basement throughout most of the Wollaston and Mudjatik Domains. To the west, in parts of the Mudjatik and Virgin River Domains, it appears to be associated with basic-ultrabasic intrusives and/or volcanics and oxide-silicate facies banded iron formation.

3) A thick unit of calcareous and non-calcareous meta-arkoses, which are interlayered with subordinate calc-silicates and thin pelite horizons.

4) An upper amphibolite-quartzite unit characterized by these two rock types and containing interlayered calcareous sediments and graphitic pelites. This unit is essentially synonymous with the Hidden Bay assemblage (32, 33) and is only known to outcrop in the Wollaston Lake area.

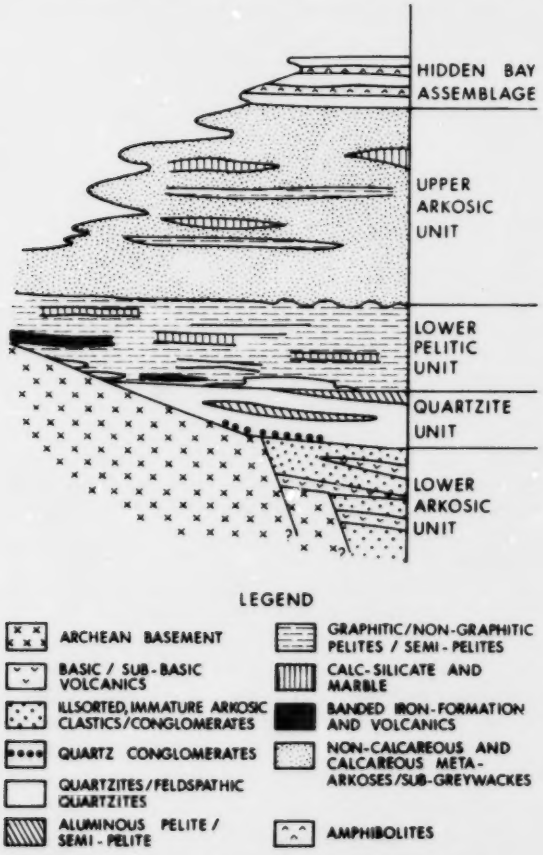

***Figure 4** - Generalized stratigraphic relations in the Wollaston Group. The right of the column is applicable to the eastern Wollaston Domain, the left to the western Wollaston and Mudjatik Domains (after Lewry and Sibbald, 5)).*

South of the Athabasca Basin the zone displays non-linear structural style in its core (Mudjatik Domain) and linear character marginally (Virgin River and Wollaston Domains). This symmetry is enhanced by development of major bounding shear zones (Needle Falls and Virgin River-Black Lake). Metamorphic grade is highest in the core of the zone, reaching hornblende granulite facies, and falls off rapidly only close to the shear zones.

The zone is interpreted as a region of miogeoclinal Aphebian sedimentation which has undergone intense Hudsonian (sensu lato) orogenesis, marked by high grade metamorphism and accompanying ductile interaction of the Archean cratonic basement and the Aphebian supracrustals. Structural evolution is complicated and three main deformation events are recognised (5, 6). The Mudjatik Domain representing the most mobile core of the zone developed flat-lying granitoid migmatite lobes (nappes) separated by screens of infolded supracrustals, whereas mantled gneiss domes formed in the cooler marginal Wollaston and Western Virgin River Domains (Fig. 5). In the Wollaston Domain the domes comprise granitoid Archean cores dated at around 2500 Ma (U-Pb, zircon method) (34) enveloped by Aphebian supracrustals retaining their stratigraphic integrity. Subsequently, in the zone as a whole, longitudinal (D_2) and lateral (D_3) compression resulted in dome and basin (non-linear) interference folding of the recumbent nappes in the core and flattening of upright gneiss domes into doubly plunging antiforms in the margins.

Northeast of the Athabasca Basin, along the Northwest Territories - Saskatchewan border, the existence of Aphebian supracrustals and Archean basement of low metamorphic grade suggests that the mobile infrastructure of the Cree Lake Zone plunges to deeper levels, well below the current erosional surface and Archean-Aphebian interface.

The Martin Group

The Martin Group unconformably overlies the metamorphic basement in the Uranium City and Tazin Lake areas (Fig. 1). It comprises a sequence of red beds which are folded on a large scale and faulted, but are

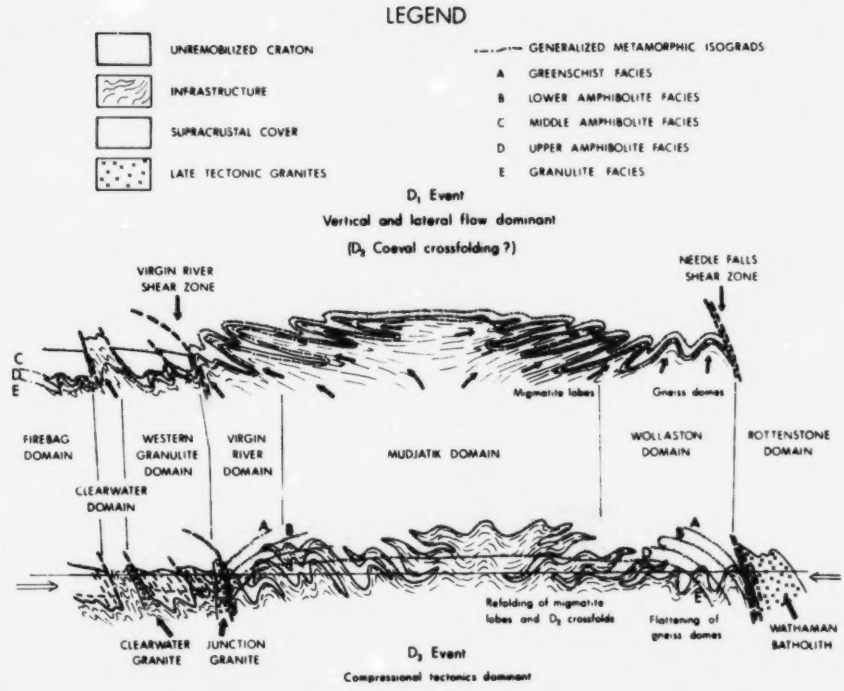

Figure 5 *- Schematic cross-section showing thermotectonic evolution of the southwestern Saskatchewan Shield and the relationship between different domains (after Lewry and Sibbald, 5]).*

unmetamorphosed. The Group outcrops in fault bounded basins. The largest of these, the Martin Lake Basin, contains around 5000 m of immature sediments and basic volcanics and is intruded by gabbroic sills and dykes. Within it, the formations identified (35, 36) (Table III) comprise a generally fining upward sequence, from coarse gravels and talus deposited adjacent to active faults at the base, to silts laid down in ephemeral lakes at the top. The sequence may reflect a reduction in elevation of the source area and/or scarp retreat and thence more distal sedimentation (36).

The volcanics are alkaline basalts and trachybasalts (37) and are only present in the Martin Lake Basin. They have been dated by the K-Ar method at 1630±180 Ma (38), whereas the sills have yielded an age of 1410±100 Ma (39). It appears likely however, that the Martin may be significantly older, predating the earliest generation of epigenetic pitchblende mineralization at 1780±20 Ma (23) but post-dating the latest orogenic events at around 1850 Ma. Similar rocks underlying the Thelon Formation in Northwest Territories yield ages around 1800 Ma (40, 41, 42, 43).

Thus the Martin was deposited in the closing stages of Hudsonian (sensu lato) orogenesis marked by uplift, faulting and formation of successor basins. A low depositional latitude around 16ºN is indicated by paleomagnetic studies (44).

Table III - Formations of the Martin Group (Martin Lake Basin), Lithology and Thickness

Formation	Lithology	Thickness (m)
Melville Lake Fm.	Siltstones, minor interbedded conglomerates and sandstones rare stromatolites	80
Seaplane Base Fm.	Interbedded, well sorted conglomerates, sandstones and siltstones	1800
Gillies Channel Fm.	Basal conglomerate, arkosic sandstones, mafic lava flows and sills	2100-2900
Beaverlodge Fm.	Basal conglomerate/breccia, arkosic sandstones and siltstones	1600

The Athabasca Group

Following Hudsonian (sensu stricto) orogenesis and late stage crustal adjustments the crystalline basement was extensively weathered. The paleoweathering profile, now preserved below the Athabasca Group, is typically around 50 m thick and has mineralogical and chemical characteristics similar to those of present day laterites (31, 45). A mineralogical zoning, with kaolinite in the upper levels and illite and chlorite in the lower, is common. Hematite is pervasive in the upper part of the profile. Superimposed alterations marked by the removal of hematite and emplacement of chlorite variably influence the weathering profile and represent post Athabasca Group hydrothermal effects.

Table IV - Formations of the Athabasca Group: Distribution, Depositional Environment, Provenance and Thickness

Depositional Environment	West		East	Source Area	Thickness (m)
	Jackfish Basin	Mirror Basin	Cree Basin		
Marine	Carswell Fm.				?
Marine	Douglas Fm.				?
Marine	Tuma Lake Fm.			NE ?	100
Marine	Otherside Fm.	Otherside Fm.			200
Marine	Locker Lake Fm.	Locker Lake Fm.		S, E, NE	75-200
Marine	Wolverine Point B	Wolverine Point B		S, E	100-300
Marine	Wolverine Point A	Wolverine Point A	Wolverine Point A	S	100-200
Marine		Lazenby Lake Fm.		S	100
Nonmarine	Manitou Falls D	Manitou Falls D	Manitou Falls D	E, NE	]
Nonmarine	Manitou Falls C	Manitou Falls C	Manitou Falls C	E, NE, S?	] 1000
Nonmarine			Manitou Falls B	E, NE, S (minor)	]
Marine	Fair Point Fm.	Manitou Falls A (Marine in part)		local; S,E ?	300 (FP) 400 (MFA)

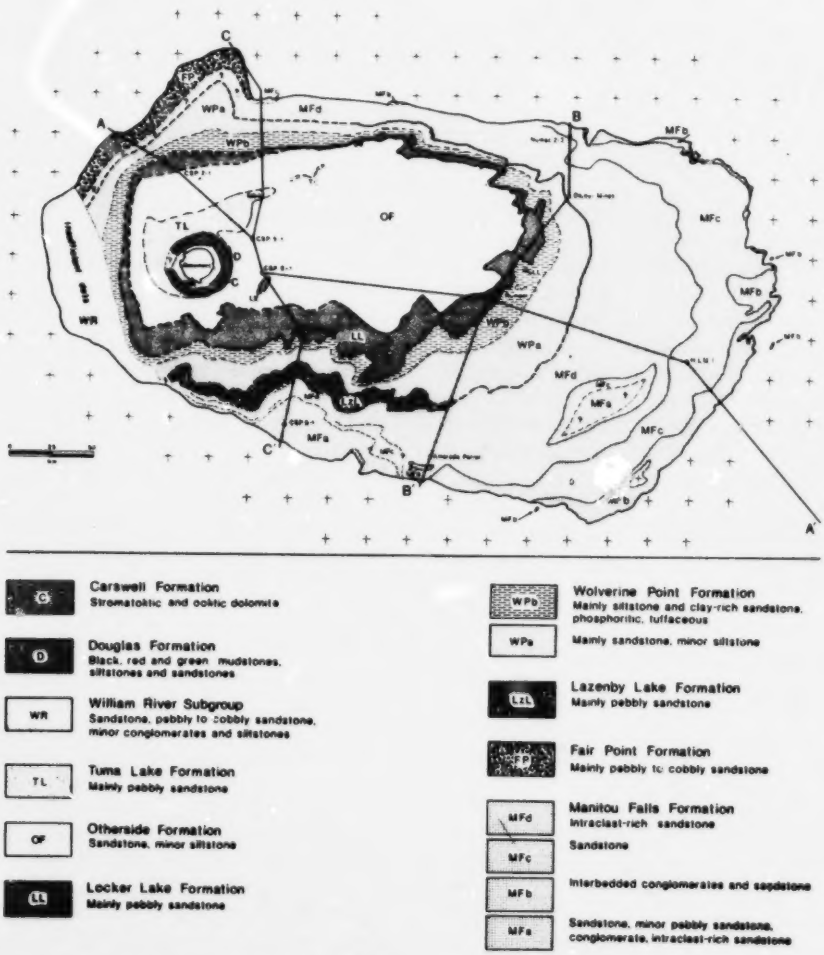

***Figure 6** - Geological map of the Athabasca Basin. Locations of cross-sections (Fig. 7) also shown (after Ramaekers, 1981).*

Renewed instability, uplifts and subsidence along established Hudsonian structures, led to deposition of a series of largely transgressive deposits whose remains form the Athabasca Group. The Group covers some 100 000 km^2 and comprises a 1400 m thick fining upward clastic succession capped by dolomite. A stratigraphy has been established by Ramaekers (46, 47, 48) (Table IV). Four marine transgressive sequences and one regressive fluvial wedge are recognised.

Deposition occurred within three northeasterly trending sub-basins (Figs. 2,6,7) initially outlined by seismic studies (49). Marine sandstones (Fair Point Fm.) were first laid down in the most westerly lying Jackfish Basin and fluvial and marine sandstones, pebbly sandstones and conglomerates (Manitou Falls Fm. unit A) in the Mirror Basin. Coarse alluvial fans (Manitou Falls Fm. Unit B) developed in the Cree Basin. These graded westward into more distal, progressively finer, braided stream deposits (Manitou Falls Fm. units C and D), giving rise to a fluvial wedge up to 1000 m thick. A second marine incursion into the Mirror Basin is marked by pebbly sandstones of the Locker Lake Formation and later overlapping Wolverine Point Formation sands, silts and muds. The upper part of the Wolverine Point Fm. (B unit) is finer grained and typified by phosphates, which rarely contain preserved tuffs. Later marine transgressions are represented by pebbly sandstones of the Locker Lake Formation and possibly also the Tuma Lake Formation. The Douglas and the Carswell Formations are the uppermost units of the exposed sequence and respectively comprise shallow marine sandstones, siltstones and mudstones, and oolitic and stromatolitic dolomites.

Four main source areas are suggested to have supplied sediment to the Athabsca Basin. Initial deposition of the basal Fair Point Formation was dominated by local source material, whereas later formations derived detritus from the northeast, east and south (Table IV).

The marine clastics were laid down in shallow seas which were probably warm, as indicated by the dolomites of the Carswell Formation. The fluvial plains to the east were subject to aeolian action, as evidenced by well rounded sand grains and ventifacts in the conglomerates.

The tuffaceous unit of the Wolverine Point Formation has been dated at 1430 to 1450 Ma by the Rb-Sr isochron method and a depositional age around 1450 is indicated (11, 50).

The Athabasca Group clastics comprise predominant orthoquartzite characterized by a clay (kaolinite, illite) rich matrix and by a variable hematite content. Their purity caused Fahrig (51) to argue that the sandstones are supermature multicycle sediments. However, others (48, 52) have suggested that the clays and hematite are authigenic and that the sandstones once contained feldspars and mafic minerals which have been

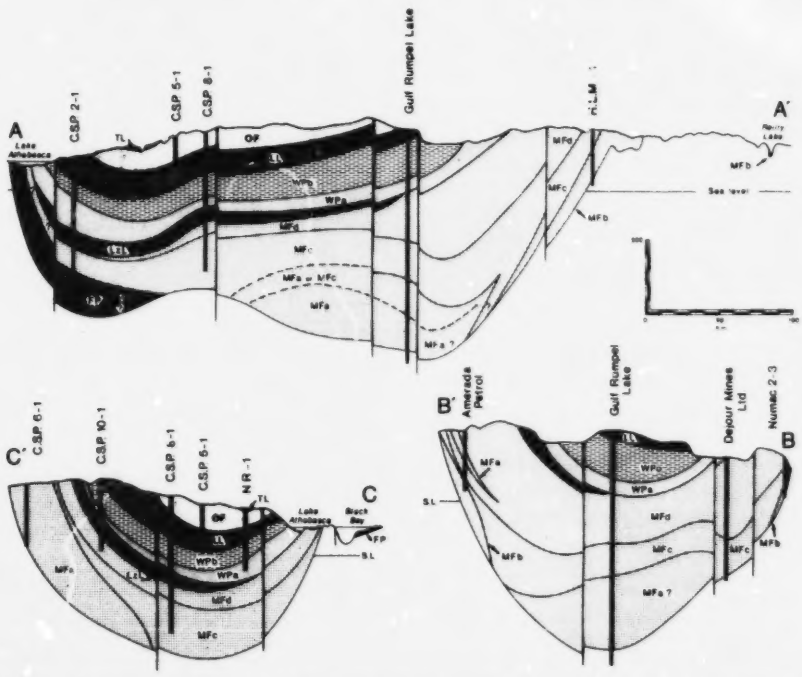

Figure 7 *- Cross-sections through the Athabasca Basin. Locations, of sections and legend shown in Fig. 6 (after Ramaekers, 48]).*

diagenetically altered. Rarely preserved relicts of the original detrital assemblage in early cemented zones, alterated mafic dykes and paleomagnetic data from hematized sandstone samples (53, 54, 55) have been argued to favour this contention.

Mafic dykes

The Athabasca Group is cut by a series of northwesterly trending mafic dykes. Although poorly exposed, they are often well defined as linear magnetic highs. The intrusives range in size from a metre or less to several hundred metres wide and comprise ophitic textured, plagioclase-augite aggregates, with up to 15 percent magnetite and minor olivine, pigeonite apatite, orthoclase, quartz, biotite, chlorite and hornblende. Adjacent to dykes the sandstone is altered, by bleaching and silicification and locally exhibits columnar jointing (56). The most reliable ages for emplacement are provided by Rb-Sr mineral isochrons at 1310±70 Ma and 1160±40 Ma (50). K-Ar ages ranging between 1230 and 938 Ma (57, 58, 59, 60) have also been obtained.

Uranium Mineralization in Northern Saskatchewan

The majority of uranium occurrences, and all yet proven to be economic, lie to the west of the Needle Falls Shear Zone. This distribution is not considered fortuitous, rather it reflects the major differences in crustal evolution of the areas on either side.

To the east of the shear zone uranium mineralization is confined within granites and granite pegmatites of presumed Hudsonian (sensu lato) age, whereas to the west, a diversity of deposits and deposit ages is apparent. For example, differing types of uranium mineralization of Lower Proterozoic age are present in the Western Craton and in the Cree Lake Zone. Yet another type, the most important economically, is seen in the younger Athabasca Basin uranium deposits which straddle the unconformity at the base of the Athabasca Group.

In the Western Craton uranium mineralization appears most commonly in 'linear zones' of Hudsonian (sensu lato) thermotectonic reworking. Following Beck (19), both syngenetic and epigenetic types are recognized, the latter occurring as veins and unusually as disseminations.

The syngenetic mineralization manifests itself as disseminations of radioactive minerals in granite pegmatites and, less commonly, in country rocks. Uraninite, the typical ore mineral, is usually associated with monazite and thorite. Rare earth minerals are locally present, but are only important in the pegmatites. U-Pb dating yields an age for the syngenetic deposits in the Beaverlodge area of 1930±40 Ma (23).

The epigenetic mineralization occurs as fracture controlled, pitchblende vein deposits. These provided the source for uranium production from the Beaverlodge area (Fig. 1, Table I). The epigenetic deposits can be divided into two groups showing simple and complex mineralogy respectively (19, 61).

In the former, which are the more common and exemplified by Eldorado's Ace-Fay-Verna orebodies, pitchblende is accompanied by coffinite, brannerite, nolanite, pyrite, chalcopyrite and galena, whereas in the latter, illustrated by the Nicholson ore zones, pitchblende occurs with coffinite, thucolite, sulphides, arsenides and selenides of nickel, cobalt, copper, lead and zinc, and native gold and silver. U-Pb dating has identified four pitchblende forming or reworking events in these deposits at 1780±20 Ma, 1110±50 Ma, 270±20 Ma and 0-100 Ma (23).

Hoeve and Sibbald (31) emphasized the geochemical similarity between deposits of complex mineralogy, in the Beaverlodge area, and those of unconformity type, in the Athabasca Basin, and proposed two main episodes of epigenetic uranium mineralization. The first, at 1780 Ma, gave rise to the Beaverlodge deposits of simple mineralogy, whereas the second at 1100 Ma resulted in reworking of these deposits and in formation of new ores of complex mineralogy both at Beaverlodge and in the Athabasca Basin.

Evidence to support this hypothesis is provided by the U-Pb age dates, obtained from deposits of both simple and complex type (23), and the recognition of a potential association between the Nicholson ore zones and the sub-Athabasca unconformity (2). Alteration chemistry and fluid inclusion characteristics are also indicative of unconformity origin (3) for at least some deposits of complex mineralogy in the Beaverlodge area.

The early generation of epigenetic pitchblende exhibits a strong structural control, occurring in the fractured wall rocks of major faults, which themselves may cut rocks which have undergone earlier mylonitization during Hudsonian (sensu lato) orogenesis.

By contrast, the Cree Lake Zone is characterized by uranium mineralization which exhibits lithological and stratigraphic, rather than structural, controls. Some mineralization is present within granitic and pegmatitic anatectic fractions within the remobilized Archean basement, however, more commonly occurrences are located within the Aphebian, Wollaston Group, supracrustals (Fig. 4). On the basis of dominant host rock, Sibbald et al. (62) and Lewry and Sibbald (63) distinghish arkosic, pelite-pegmatite and calc-silicate types of deposits. Occurrences of the first two types are for the most part located near the base of the Aphebian succession, whereas those in calc-silicate rocks are encountered at several stratigraphic levels. These deposits are of sub-economic grade and are deemed to represent 'syngenetic' mineralizations which have been subjected to metamorphism and/or anatexis. Recent analogs might be sandstone type deposits and black shale and sabkha related uranium concentrations (64).

The absence of Hudsonian epigenetic vein type mineralization in the Cree Lake (Mobile) Zone is believed

to reflect its contrasting thermotectonic evolution relative to the Western Craton. The Zone was subjected to ductile, rather than plastic and brittle Hudsonian (sensu lato) deformation. The resultant absence of structural traps and the high grade metamorphic conditions precluded the development of Hudsonian fracture controlled vein type pitchblende deposits. The most easterly known occurrence of this type of mineralization is the Nisto showing (Fig. 2), located in the mylonites of the Black Lake Shear Zone, at the eastern margin of the Western Craton.

The important unconformity-type deposits are confined to the Athabasca Basin which covers portions of both the Cree Lake and the Western Craton. The Cluff Lake deposits are located within the Western Craton, the other main deposits within the Cree Lake Zone. Mineralization seems to have been controlled by the presence of the sub-Athabasca unconformity, rather than by factors related to Aphebian (Lower Proterozoic) sedimentation or Hudsonian (sensu lato) structural and metamorphic evolution, because outside the Athabasca Basin no such mineralization is encountered.

Athabasca Basin Unconformity-Type Deposits

The geological characteristics of these unconformity-type deposits are summarized in Table V and below and illustrated by cross-sections of Rabbit Lake, Collins Bay B zone and Midwest Lake (Figs. 8, 9, 10, 11). The deposits bear a clear cut relationship to the sub-Athabasca Group unconformity. The highest grade ore often straddles the unconformity, as at Midwest, McClean and Cigar Lakes, although mineralization may extend for hundreds of metres above (Midwest and Cigar Lakes) and below it (Rabbit Lake, Raven, Horseshoe and Eagle Point) (Table II). There is also an undeniable association with graphitic basement rocks which are characteristic of, though not restricted to, the basal and lower parts of the Aphebian (Wollaston Group) supracrustal succession throughout the Cree Lake Zone. At their intersection with the sub-Athabasca Group unconformity these rocks may host or underlie mineralization. As such there is an apparent basement stratigraphic control.

Graphite content within the basement gneisses, which are generally of pelitic composition, may vary from a few percent as at Rabbit Lake (31) to a few tens of percent as at Key Lake (64). Accordingly these units respond weakly, if at all, or strongly to electromagnetic survey methods. In detail, the spatial relationships between graphite and mineralization is less distinct, in that ore grade and graphite concentration are unrelated, (31, 64, 65) and the bulk of the mineralization is displaced and may occur in non-graphitic basement rocks or in the Athabasca Group.

In many deposits there are clear major structural controls. Mineralization can often be related to faults, which displace the sub-Athabasca Group unconformity by several tens of metres. At Rabbit Lake, Key Lake and the Collins Bay A and B zones reverse faults are characteristic (Figs. 8, 9, 10) (31, 64, 65), whereas at Midwest Lake normal faulting is inferred (Fig. 11) (66, 67). These structures may occur singly, or in imbricate zones (66, 68), and strike northerly to east-northeasterly, dipping moderately to steeply in either direction. Contacts between major units of graphitic pelitic and granitoid gneisses, which represent a major structural anisotropy, are preferred locations for these faults, as for example at Key Lake and the Collins Bay A and B zones (30, 33, 65). In several deposits (McClean and Dawn Lake), there is no obvious displacement of the unconformity, although the basement below mineralization appears structurally disturbed (69, 70).

A number of deposits occur on linear topographic basement highs showing a relief of a few metres (McClean, Midwest, Dawn and Cigar Lakes). These 'bumps' appear to have been features of the pre-Athabasca Group land surface, although there has been and continues to be debate as to their origin (69). Evidence for a pre-depositional origin is provided by the observation that basal conglomerate layers at Midwest and Dawn Lakes wedge out against the ridges (Fig. 11) (70). The development of pelitic ridges, while an irregularity to geologists familiar with temperate weathering environments, may be compatible with the tropical weathering lateritic conditions, which characterized the pre-Athabasca land surface. Under such conditions, relative to felsic rocks, those rich in phyllosilicates tend to weather resistently. A modern example is provided by the 'arena granites' of Uganda in which granite plutons form a depressed area rimmed by quartzites and argillaceous sediments (71).

Solution features have been recognized as adding to the structural complexity of deposits, both in the basement rocks and Athabasca Group. In the Rabbit Lake deposit secondary carbonate and quartz and alteration breccia occur within and around the ore zone. Repeated tectonic fracturing, solutioning of dolomitic marbles, collapse and mechanical infilling of open spaces have likely contributed to the lithologically and structurally chaotic alteration zone (Fig. 8) (31, 72, 73).

Table V - Geological Characteristics of Athabasca Basin Unconformity-Type Uranium Deposits

Proximity to the Sub-Athabasca Group unconformity
Proximity to graphitic rocks in the crystalline basement
Structural controls: a) Post-Athabasca Group thrust faults b) Basement relief ('bumps') c) Solution collapse structures in basement (carbonates) and in Athabasca Group (quartz-sandstones)
High grade: up to 12 percent U
Primary uranium minerals: pitchblende and coffinite
Complex mineralogy and geochemistry, but variable concentrations of associated elements (U + Ni, Co, As, Cu, Mo, Pb, Zn, Fe, V, Ag, Au, Pt, Se, S)
Glassy hydrocarbons present in the ore
Extensive alteration envelopes: Mg - chloritization, Mg - tourmalinization, hematization, illitization, silicification and dolomitization
Age of initial mineralization (@ 1300 Ma) postdates deposition of the Athabasca Group (@ 1450 Ma)

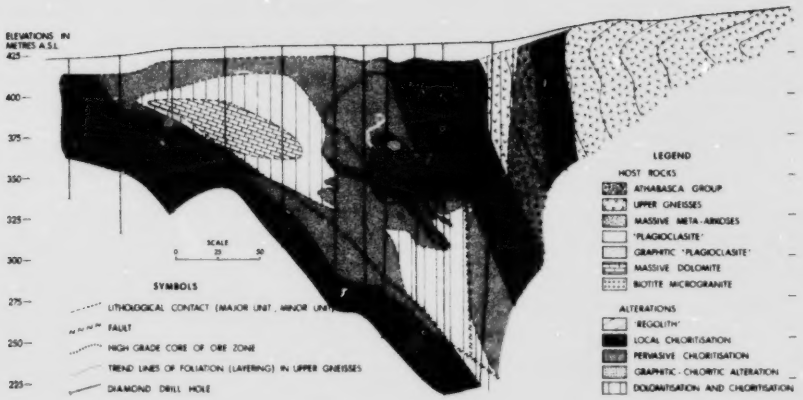

Figure 8 *- Geological cross-section of the Rabbit Lake deposit illustrating primary and alteration lithologies (after Sibbald, 73]).*

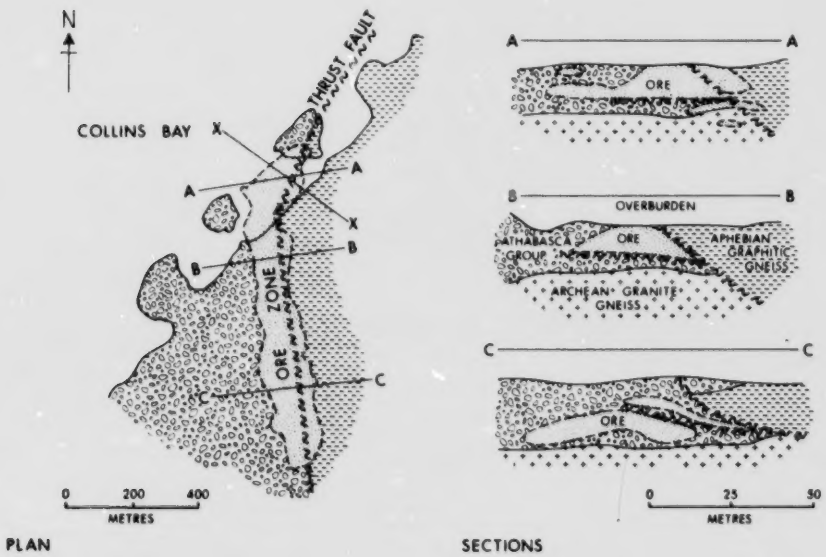

Figure 9 *- Schematic plan and cross-sections of the Collins Bay B zone. Location of cross-section (Fig. 10) denoted XX (after Jones, 65]).*

The Athabasca Group, when it overlies or contains uranium mineralization invariably shows evidence of quartz grain corrosion. Sandstones become friable, clay enriched and transected by clay filled fractures (69, 74, 75). On top of high grade pods, as at Midwest and Cigar Lakes, massive clay caps are developed (Fig. 11). If, as is suggested by these observations, the increased clay content, within and adjacent to mineralized zones, results from residual sandstone-matrix clay enrichment, then significant volume decrease must have occurred in the Athabasca Group. At Midwest Lake, in particular, there is evidence of accompanying collapse in that a conglomerate marker horizon overlying the high grade pod shows a downward 'sag' of over 20 m (Fig. 11). Similar relationships are observed above high grade pods at Dawn and McClean Lakes (69, 70). Extensive fracturing of the sandstones and, in some cases, zones of brecciation showing rotation of sandstone fragments may also be apparent. The intensity of fracturing is noted to correlate with the intensity of mineralization, but not with uranium grade (69).

The unconformity-type deposits are often of extremely high grade and marked by a very diverse mineralogy and geochemistry. Intersections of tens of percent are relatively common. Pitchblende and coffinite, the primary uranium minerals, are accompanied by pararammelsbergite, rammelsbergite, niccolite, gersdorffite, millerite, carrollite, molybdenite, various copper sulphides, clausthalite, galena, sphalerite, hematite, goethite, psilomelane, native copper, gold and selenium, and others. Gangue minerals comprise quartz, calcite, dolomite, ankerite, siderite, chlorite, sericite and adularia. Geochemically uranium is accompanied by Ni, Co, Mo, Cu, Pb, Zn, Mn, Fe, V, Ag, Au, Pt-group elements, S, Se and As.

In some deposits (Rabbit Lake and Cluff Lake - N and Claude zones) elements associated with uranium occur in trace amounts, whereas at others they are present in mineable quantities. For example, the D zone at Cluff Lake contains significant selenium and gold (76). Key, McClean, Midwest, Cigar and Dawn Lakes and the Collins Bay B zone have considerable nickel and arsenic and the Collins Bay A zone also silver and gold (64, 65, 67, 69, 70). Mineral and geochemical zonation occurs within deposits, as at the Key Lake Gaertner orebody where niccolite and massive lustrous pitchblende give way upward to sooty pitchblende and millerite (64). At the Collins Bay B zone, the bulk U/Ni ratio of the orebody increases from north to south in harmony with a change in sandstone colour from grey to green (74). However, it is at McClean Lake that mineralogical and geochemical variations are most clearly documented (69, 77) and ascribed primarily to Eh gradients within the ore zones. It is suggested that the U/Ni ratio can be used qualitatively as an indicator of paleo-redox potential, varying sympathetically with Eh, as can the transition from arsenide to sulphide to oxide dominated mineralogy. Similarly, the bulk variation between deposits can be explained as a function of bulk oxidation state, the geochemically most simple deposits being associated with a more oxidized environment.

Solid, glassy, amorphous hydrocarbons are present in most, if not all, deposits. They occur in mineralized rock, intimately associated with ore, as well as in unmineralized rocks of the alteration envelope. In some deposits, like the Collins Bay B zone and the D zone at Cluff Lake, they are present in appreciable amounts. At Rabbit Lake, hydrocarbon buttons are most abundant in high-grade ore, but also occur in vein fillings on top of euhedral quartz in the alteration envelope (31). The association of hydrocarbons with mineralized and altered rocks suggests a reducing agent capable of precipitating hydrocarbon in the ore forming process. In this respect, Pagel (78) has reported carbon dioxide, methane and ethane as present in gangue quartz from Rabbit Lake.

Deposits are surrounded by extensive alteration envelopes influencing both the Athabasca Group and crystalline basement. Alteration is distinct from that which characterizes the sub-Athabasca weathering profile and is variously marked by chloritization, tourmalinization, hematization (several episodes), illitization, silicification and dolomitization. Other processes operative within alteration zones are the destruction of graphite, corrosion of quartz and formation of residual clay seams and caps above mineralization in the Athabasca Group, bleaching (removal of hematite) and development of euhedral quartz $\pm$ siderite $\pm$ pyrite $\pm$ hematite filled fractures. For example, at Rabbit Lake, where ore occurs wholly in basement rocks, Mg-chloritization and Mg-tourmalinization (dravite) are characteristic and reflect large scale introduction of magnesium and boron probably derived from solutioning of dolomitic marbles. Silicification and dolomitization are also locally important yielding irregular porous vuggy zones of secondary quartzite and carbonate. Graphite is visibly destroyed throughout part of the alteration zone (Fig. 8) (31). At the Collins Bay B zone, feldspars and mafic minerals in basement rocks adjacent to the Collins Bay thrust are replaced by illite and chlorite. In the Athabasca Group, approaching the ore zone, matrix clays of the sandstones represented by a broadly equally mixed illite/ kaolinite assemblage (background) are transformed to one dominated by illite (79). Development of an early generation of earthy red hematite, bleaching, quartz corrosion and formation of clay seams are other characteristics of the alteration zone (Fig. 8) (74, 75). Similarly, at Midwest Lake, Sopuck et al. (80) and Hoeve (81) have documented an illitization halo around the ore zone respectively by geochemical and XRD methods. Below the ore zone illitization and chloritization influence both fresh and lateritically weathered basement, as do bleaching quartz corrosion and graphite removal (Fig. 11). In the Athabasca Group illitization, bleaching, quartz corrosion, and formation of clay seams and a clay cap to mineralization are characteristic. In cross section, the alteration zones in the basement and Athabasca Group are funnel and inverted funnel shaped respectively and

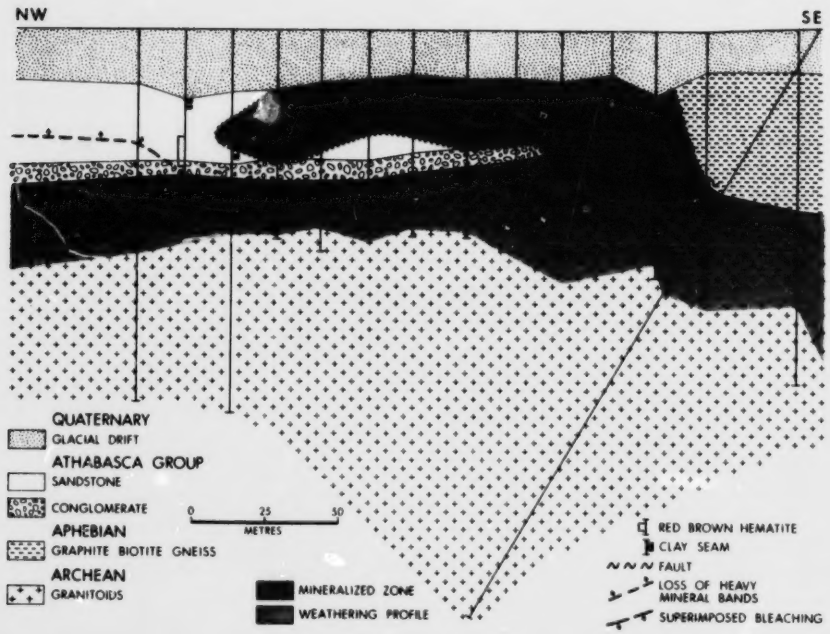

Figure 10 *- Geological cross-section of the Collins Bay B zone illustrating, red brown hematite and clay development, bleaching (loss of hematite) and destruction of heavy mineral (hematite) banding in proximity to the mineralized zone (after Sibbald, 75]).*

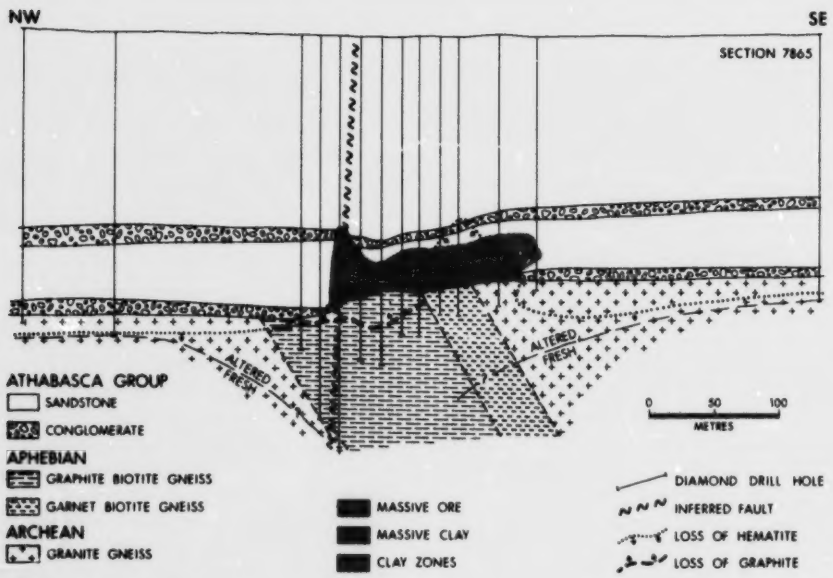

Figure 11 *- Geological cross-section of the Midwest Lake deposit illustrating bleaching (loss of hematite) of the Athabasca Group and weathered basement and loss of graphite from the graphite-biotite gneiss underlying the deposit.*

show their widest extension at the unconformity. Of particular interest to explorationists is the fact that they extend both vertically and laterally well beyond mineralization, and thereby enlarge potential drilling targets by a factor of 10 to 20 times (81).

Within the alteration zones, whose character is shaped by the introduction/removal of K, Mg, Fe and SiO_2, trace metals generally show only limited dispersion around mineralization. For example, uranium values may vary from a few percent to a few ppm over metres. However, at McClean Lake a 'chimney' of uranium values of 2-3 ppm U occurs in the Athabasca Group (background 1 ppm U) to the present erosion surface, 150 m above mineralization, as does the illitization halo (69). At Midwest Lake, uranium and boron and at Key Lake uranium and lead are enhanced around mineralization, but not as widely as the major element alterations (80).

Age dating studies have yielded a wide range of numbers of varying quality for deposit formation. U-Pb, Pb-Pb and Sm-Nd data from pitchblende in several deposits serve to indicate that primary mineralization occurred around 1300 Ma. Samples identified as 'early' or 'first stage' pitchblendes commonly yield discordant ages defining various discordia intersecting concordia between 1250 and 1350 Ma (82, 83, 84 (Key Lake); 85, 86 (Rabbit Lake); 60, 87 (Midwest Lake); 88 (Collins Bay B zone)).

This age is recorded in illites from alteration zones adjacent to mineralization, using Ar-Ar (69); Rb-Sr (60) and K-Ar (25) dating methods.

The pitchblende data also indicate a second event, equated with initial mineralization in some deposits and remobilization of pitchblende in others, at around 1100 Ma (85, 86, 89 (Rabbit Lake); 60, 87 (Midwest Lake); 90 (Cluff Lake)). This event appears coeval with that identified by Koeppel (23), as a period of new pitchblende deposition or reworking (lead loss) in the Beaverlodge area (23). Koeppel also recognized younger periods of lead loss at around 300 Ma and between 100 Ma and the present day.

The more recent isotopic data from the Athabasca Basin deposits has confirmed these youngest events (84, 86, 87, 91). The former may represent a period of basin uplift. Ground waters gained access to mineralization causing redistribution of uranium in conjunction with kaolinitization, as, for example, at Key Lake (80, 86).

Deposit Model

Several genetic models have been proposed for the Athabasca Basin unconformity type uranium deposits. They fall into four categories, discussed by Hoeve et al. (52):

a) near surface supergene
b) magmatic hydrothermal
c) diagenetic hydrothermal
d) multicycle/process

Over time the diagenetic-hydrothermal model (31) has found increasing acceptance among geologists as well as support from deposit studies. Recently it has been newly presented in a more elaborate form as the Reductant Plume Model (69).

The model (Figs. 12, 13) invokes the interaction of the crystalline basement and the Athabasca Group through the mixing of fluids of contrasting chemistry. Oxidizing brines of the Athabasca Group aquifer entered the basement along fractures, reacted with the wall rocks and re-emerged with reduced character. At, or in close proximity to the unconformity, they mixed with the aquifer creating a dynamic but essentially stationary redox front around a reductant plume displaced downstream by the flow of the aquifer (cf. Collins Bay B zone (Figs. 9, 10).

Conditions of deposit formation suggesed by fluid inclusion studies (92, 93, 94) are: T 150-225°c, P 0.7-1.5 kb salinity ca. 30 per cent NaCl, implying an elevated geothermal gradient in excess of 30°C/km. The reducing fluids emanating from the basement were probably charged with CO_2, CH_4, H_2S, Fe, K and Mg, whereas the aquifer contained U, Ni, Co, As, Cu, Zn etc. Debate continues as to the relative contributions to the deposit of the reducing and oxidizing fluids (52, 69).

Quartz solutioning of the Athabasca Group sandstones must have been caused by basement fluids undersaturated with respect to silica, and thence hotter or more alkaline than the aquifer. The former appears more probable. In this respect the steeply dipping graphitic units may have formed linear hot spots in the Basin floor transporting heat from greater depth by virtue of their superior thermal conductivity (95).

Discussion

The model has numerous implications from a mineral exploration viewpoint and on a broader scale for establishing parameters for recognition of a uranium province:

1) Deposit formation is dependent on the interaction of large volumes of fluids with dilute metal concentrations. Other factors aside, probability of mineralization increases with proximity to the fluid source, the formational brines of the Athabasca Group. To date, unconformity type mineralization has not been detected in excess of 1000 m vertically below the sub-Athabsca Group unconformity.

2) Deposits are formed by stripping of metals from the aquifer. For effective free circulation, and thence opportunity for basement interaction, the Athabasca Group must have been or become thoroughly oxidized. The unconformity deposits can be

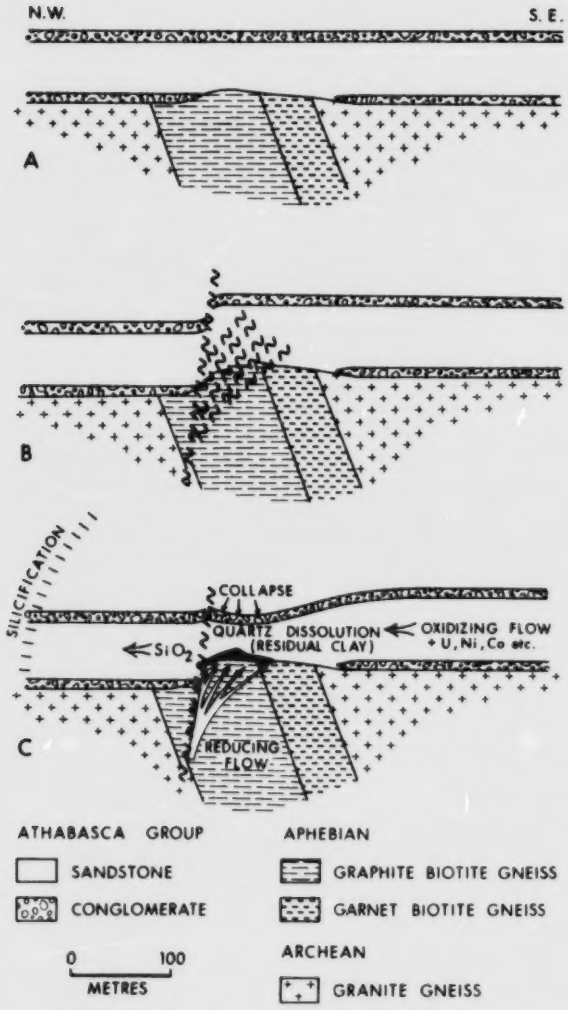

***Figure 12** - Model for evolution of Midwest Lake uranium deposit. A - non-deposition of basal conglomerate over pelitic basement ridge. B - faulting of basement pelite and Athabasca Group. C - interaction at fault of reduced basement fluids and the Athabasca Group aquifer. Quartz solutioning at basement outflow causes residual clay enrichment, collapse and by implication redeposition of silica (silicification) in the adjacent sandstones.*

considered as a class of sandstone type deposits occurring when a basin has been totally flushed. This condition would be achieved most easily in basins containing clean and poorly stratified quartz sandstones, free of plant derived detritus (pre-Devonian) and subjected to diagenesis for a long time period (96). The flushed sandstone basins would be depleted in trace metals, as the Athabasca Group and appear as negative geochemical anomalies. Hence their response to airborne radiometric surveys will be minimal.

3) Metalliferous waters of the Athabasca Group aquifer are cycled through fractures in the basement to provide, through reaction with the wall rocks, a reducing fluid. There are thus two theoretical possibilities for deposit formation at the basement interface, at points of fluid ingress and egress. Deposits interpreted to be of the former type (Eagle Point, Cluff Lake-Claude and N zones) are typically of lower grade (<1 percent U), geochemically simple and less reduced than those of the latter type (Key Lake, Midwest Lake, Collins Bay B zone), reflecting the different efficiencies of the fluid-solid, fluid-fluid deposit forming processes.

4) Outflow of reductant along fracture trends, by analogy with spring lines developed at the present land surface, likely concentrated in specific locations yielding a series of reductant plumes and thence pods of mineralization. Deposit morphology and complexity are governed by relative flow rates of the fluids and flow variations through time. Mineralization may encroach on the aquifer or vice versa leading to several reduction-oxidation cycles and complex mineral parageneses.

5) Activation of a mineralization cycle requires that brines of the Athabasca Group aquifer gain access to the basement along fractures. Mineralization is temporally sporadic and related to periods of tectonic instability of the basin manifested by faulting and mafic dyke emplacement. In this respect, the broad temporal correlation between deposit formation and the mafic dykes is well documented by age dating. Once initiated the cycle continues until local porosity becomes plugged, probably in response to residual clay build up. This condition would also aid deposit preservation.

6) The model entertains a single cycle of concentration and emphasizes process rather than source. Spectacular grades result from a stationary redox condition, in contrast to sandstone hosted roll deposits which concentrate through migration. Overall, an unusually enriched source basement is neither advocated nor indicated by regional radiometric surveys (28) and lithogeochemical studies (10, 97), although locally some supracrustals and intrusive granites, as noted earlier, do contain anomalously high uranium values. The Athabasca Group is entertained as the direct source of most metals, either through destruction of feldspars and mafic minerals by interstratal leaching and/or through release, during diagenesis, of metals adsorbed to iron hydroxides and clays (47, 52).

Simple calculations illustrate that the Athabasca Group when flushed must have liberated a significant quantity of metals. For example, 1 ppm U leached from 40 km^3 of sandstones would produce the 100 000 t of uranium concentrated at Key Lake. Similarly, Ramaekers (47) notes that the Athabasca Group as a whole might have contributed some four billion tonnes of uranium metal to the basinal brines, which if impounded would have

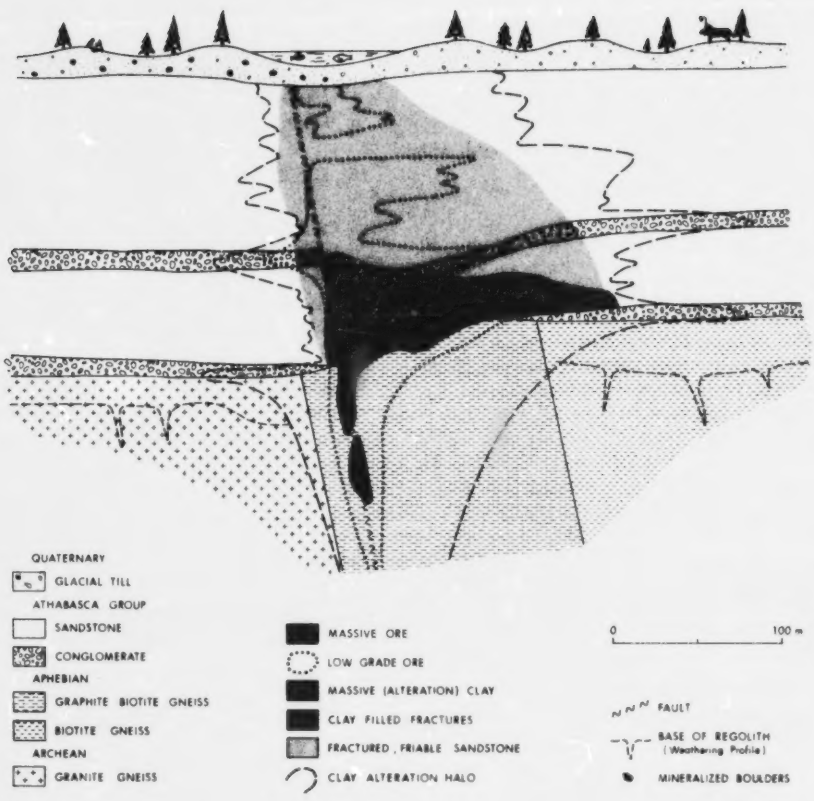

***Figure 13** - Idealized "model" Athabasca Basin unconformity-type uranium deposit.*

necessarily precipitated it somewhere. He suggests that any hypothesis that derives uranium exclusively from the basement subsequent to Athabasca Group deposition should also undertake to explain away this volume of metal.

Conclusion

In retrospect the historical record suggests that the discovery of the Athabasca Basin uranium province was a comedy of errors, although human nature dictates that there are those who will claim remarkable intuition.

In 1945, the impetus for exploration in the Beaverlodge area arose because Nicholson was one of only three known occurrences of uranium minerals in Canada. Ironically, Nicholson, now recognized as an unconformity-type deposit, led to the discovery of a wholly different group of-uranium deposits.

In the late sixties the objective was to examine a sandstone basin in a region with existing uranium production, using contemporary models for conglomerate and sandstone hosted deposits. Through prospecting of airborne radiometric anomalies, explorationists recognized a potential for mineralization in rocks underlying the sandstone basin. Despite models, the unconformity-type deposits were eventually discovered.

There are several lessons to be learnt from the above:

1) the search for mineralization has proven successful in regions where mineralization, however insignificant, has been observed before and is unexplained.

2) the exploration model, while providing a stimulus, may become a hinderance if it yields to dogma.

3) after discovery, deposit studies provide improved models for further exploration of the specific environment. However, as many factors are involved in

deposit formation, an incorrect emphasis on any one of these may lead to misdirection of effort.

4) The relevant model is one which has been rigorously and successfully applied, not one that has led to discovery through balancing the wrong approach with a large measure of luck.

Acknowledgements

The author acknowledges support of Saskatchewan Energy and Mines in preparation of this manuscript. The unending patience of Jagdish Bilkhu, in typing, and Phil Weir, in drafting, is greatly appreciated. Jan Hoeve, Bob Macdonald and Dave Thomas are thanked for valuable discussion and manuscript review.

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RESIDENT GEOLOGIST REPORTS

Mineral Exploration Activity in the La Ronge and Athabasca Mining Districts

by A.J. Gracie

Gracie, A.J. (1985): Mineral exploration activity in the La Ronge and Athabasca Mining Districts; *in* Summary of Investigations 1984, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The level of uranium exploration in the mining districts stabilized after two consecutive years of relative decline.

Gold exploration, on the other hand, increased considerably during the year. Gold exploration activity was largely in the La Ronge Domain where the Geological Survey is concentrating its efforts to provide more technical support for the mining industry. A geoscience program, funded through the Federal-Provincial Economic Regional Development Agreement 1984-89 (ERDA), consists of geological mapping and compilation, geochronological investigations, magnetic gradiometer surveys, regional lake sediment surveys, biogeochemistry, mineral deposit investigations and core collection, most of which concern the present mining area.

Grassroots exploration for platinum group elements in ultramafic and mafic rocks, being carried out by Lacana Mining Corporation Ltd., offers interesting possibilities for new mineral discoveries in the province.

Granges Exploration AB is the only company presently interested in base metal exploration in this area; although this company has two finds between Bigstone and Amisk Lakes, the level of base metal exploration remains low.

Three major all-weather highways to Rabbit Lake, Cluff Lake and Key Lake, now give access to northern Saskatchewan while major improvements to Highway 106 make travel to Flin Flon from La Ronge or Prince Albert much faster.

Gold

GSC Open File 1129 provided lists and maps of gold values obtained through reanalysis of lake sediment samples collected during a 1974 survey of the area extending from the Shield margin to Latitude 57°N and from the Needle Falls Shear Zone to the Manitoba border. Its release in late May resulted in 68,900 ha of new mineral properties being staked in this area.

Production is planned on two gold properties, the Star Lake 21 zone (Starrex Mining Corp./SMDC[1] joint venture) and the adjoining Jolu claims (Mahogany Minerals Resources Inc.). Placer Development Ltd. is now operating all programs on the Komis, EP and Seabee zones through agreements with Waddy Lake Resources Ltd. and Claude Resources Inc., while the Pezim group of companies have concluded agreements with Mahogany Minerals Resources Inc., Carina Mineral Resources Corp. and Waddy Lake Resources Inc. Their involvement in the area should ensure the funds needed to sustain exploration and development programs on some of the province's most promising gold prospects. Although junior mining companies still dominate the gold play, SMDC, BP Canada Inc., Cogema Canada Ltd. and Uranerz Exploration and Mining Ltd. are among the major mining companies interested in gold in Saskatchewan.

[1]Saskatchewan Mining Development Corporation

La Ronge Domain

Drill-indicated reserves on the Starrex Mining Corp./SMDC Star Lake property (Fig. 1) are 208,651 t grading 17.15 g/t (0.5 oz./ton) Au. The SMDC Annual Report for 1984 mentions additional reserves on the Kahn 18, Kahn 28 and Rush zones. A prefeasibility study recommended a conventional mine/mill complex rated at 200 tpd, trackless mining from a decline, blast-hole open stopes, supplementary production from shrinkage stopes, fine grinding and carbon in pulp circuits (Northern Miner, January 3, 1985). Access road construction has begun and the first 305 m of a 853 m decline ramp will be driven this year once the road is complete (Northern Miner, August 1, 1985).

Mahogany Minerals Resources Inc., which plans to bring the adjoining Jolu claims into production, has signed an agreement with Canadian Premium Resource Corporation under which the latter can earn a 50 percent interest in the property. A Mahogany Minerals news release on January 30, 1985 estimated that reserves in the Jolu property's Mallard Lake, Rod Main and Rod South zones might total 158,757 t of ore grading 21.6 g/t (0.63 oz/ton) Au (diluted 15 percent) or 24.7 g/t (0.72 oz./ton) Au undiluted. The company predicts that a major new drill program later this year will add substantially to these reserves.

The 21 Zone is an auriferous quartz lens with pyrite associated with mylonitized dykes. The Jolu drill targets are combinations of quartz veins in shear zones, shear zone intersections, and geochemical and magnetic highs. The 21 and Rod zones lie inside the compositionally zoned Star Lake intrusive.

There have been no recent attempts to extend known gold zones on the Jolu claims and the 21 zone property onto the Neyrinck venture. SMDC offered 30 percent of the Neyrinck venture for sale in the Northern Miner.

Further north in the La Ronge Domain, Placer Development Ltd. made an agreement with Waddy Lake

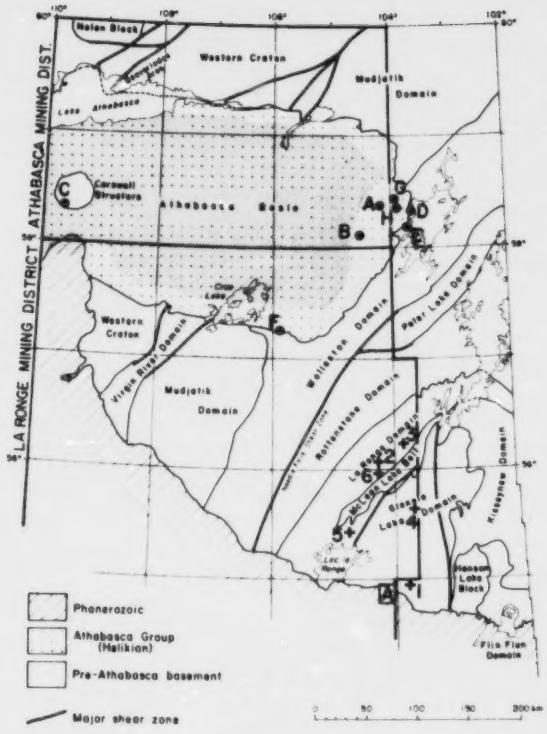

***Figure 1** - Location of the La Ronge and Athabasca Mining Districts in relation to geological domains in the Precambrian Shield.*

Current uranium mines, potential mines and major exploration locations related to the Athabasca Basin (indicated by dots): (A) Canada Wide Mines Ltd., 'Midwest Lake'; (B) Cigar Lake Mining Corp., Cigar Lake; (C) Cluff Mining Ltd., Cluff Lake; (D) Eldor Mines Ltd., Collins Bay and Eagle Point zones; (E) Eldor Mines Ltd., Rabbit Lake; (F) Key Lake Mining Corp., Key Lake; (G) Saskatchewan Mining Development Corp., Dawn Lake joint venture; (H) Minatco Ltd., 'Wolly' Project joint venture, McLean Lake Zones. Heavily patterned area approximately represents the interior of the basin where the Athabasca Group exceeds 500 m in thickness.

Current gold mine, potential and major exploration locations (indicated by crosses): (1) Carina Mineral Resources Corp., MPP 1132, Brownell Lake; (2) Mahogany Minerals Resources Inc., Mallard, Rod Main and Rod South zones; (3) Placer Development Ltd., Komis and EP occurrences, Waddy Lake; (4) Placer Development Ltd., Seabee property; (5) Saskatchewan Mining Development Corp. Sulphide-Preview-Ramsland Lakes joint venture; (6) Starrex Mining Corp. Ltd. SMDC, Star Lake.

Current base metal exploration location (indicated by box): A, Granges Exploration AB, Wapawekka Lake - Oskikebuk River area.

Resources Inc. on the Komis property. Placer must complete a feasibility study by September 1, 1989 and spend $1.5 million prior to that (Northern Miner, June 13, 1984). The EP or Eric Partridge zone lies a little to the northeast of the Komis zone on the same property. The EP zone may contain a significant tonnage of ore in the 7 g/t (0.2 oz./ton) Au range. Properties associated with the Byers Fault were largely inactive.

At the south end of the La Ronge Domain, SMDC has expanded their holdings in their Sulphide-Preview-Ramsland Lakes properties and confirmed previously known gold values in the Sulphide Lake area.. Denison Mines Ltd. is now a member of this joint venture, which is managed by SMDC. The Galena and Studer A, B and F zones make a stratiform gold target where gold is associated with lean iron formation or argillite. Last winter the joint venture tested targets in the area southwest of Preview Lake where mineralized gold zones are found within sheared gabbro (Coombe, 1984). The joint venture has obtained significant gold values in several drill holes in the Ramsland Lake area (SMDC Annual Report 1984). The better intersections in sulphide-rich layers were 3.43 g/t (0.1 oz./ton) Au over 4.35 m, 10.29 g/t (0.3 oz./ton) over 1.5 m and 30.18 g/t (0.88 oz./ton) over 0.5 m.

Glennie Lake Domain

In an agreement with Claude Resources Inc. with respect to their Seabee property, Placer Development Ltd. will make a "... $3 million pre-production recoverable cash advance to Claude, of which $2 million can be converted to a 10 percent interest in the property and $1 million, including interest can be recovered from production proceeds. Placer can earn an additional 45 percent interest in the property by: spending $2.5 million ($1 million dollars committed in the first 12 months), completing a final bankable feasibility study before July 1988, and spending the funds necessary to take Seabee to commercial production. Placer shall recover Claude's share of the project's capital costs from the proceeds of production and thereafter Placer/Claude are 55 percent/ 45 percent partners in the Seabee operation." (Claude Resources Inc. news release, July 19, 1985).

A major drill program begun by Placer in August aims to increase the Seabee ore reserves at depth and on trend from the No. 2 and No. 6 zones. The new drill program also intends to define new ore reserves in other known gold zones lying parallel and in close proximity to the main ore lenses. Drill-proven and probable geological reserves in four zones to a vertical depth of about 183 m are approximately 562,454 t averaging 18.18 g/t (0.53 oz./ ton) Au uncut, or 10.98 g/t (0.32 oz./ton) Au when the average grade across ore intervals is cut to 34.3 g/t (1 oz./ ton) Au (Gummer, 1985). Placer is also active on the three claim blocks surrounding the Seabee property, which it optioned from Currie Rose Gold Mines Ltd.

Carina Mineral Resources Corp. completed a drill program on their permit south of Brownell Lake in the fall of 1984 and this summer ran a reduced program on the Kalix zone on the east side of the permit. The Kalix zone shears, fractures and quartz veins which range up to 54.54 g/t (1.59 oz./ton) Au across 1.5 m may present an open pit mining prospect. Exploration work to date is limited to stripping, grab and chip sampling. (Northern Miner, June 20 and August 15, 1985; George Cross Newsletter, June 5, 1985). Control of Carina Mineral Corp. has now passed to the Pezim group.

Other Areas

The level of gold exploration in the Athabasca Mining District is very low. Volcanic rocks north of Stony Rapids offer an opportunity for grassroots exploration in a neglected area. These rocks are part of the Western Craton tectonic unit, which consists of retrogressively metamorphosed granulite facies rocks. Because Highway 905 to the Wollaston Lake area is within 130 km of Stony Rapids and Black Lake, access to a find in this area is no longer the problem it once was. SMDC owns MPP 1143 which covers the extension of the Ennadai volcanic belt into northern Saskatchewan at Hammill Lake.

Uranium

Uranium exploration has been mainly in the eastern Athabasca Basin and the Carswell Structure. New exploration is being directed at those areas which contain the province's three producing uranium mines at Cluff Lake, Key Lake and Rabbit Lake, and in the vicinity of the massive new find by Cogema Canada Ltd. at Cigar Lake. Uranium exploration has also expanded into areas where the Athabasca Group exceeds 500 m in thickness, although little work was carried out in the centre of the basin or along its northern or southwestern margins.

Athabasca Group Perimeter

Production at Key Lake totalled 4,000 t U in 1984 (SMDC Annual Report, 1984), while recoverable reserves as of December 31, 1985 were 71,000 t U; the company planned to produce 4,600 t U or design capacity in 1985. The Rabbit Lake ore deposit is mined out, but Eldor Mines Ltd. produced 1,361 t U from stockpiled Rabbit Lake pit ore in 1984. Production from the Rabbit Lake mill will be maintained at approximately 2000 t U per year by ore mined from the Collins Bay B zone where reserves are 12,000 t U. The company has not mined any ore from this zone yet (Eldorado Annual Report 1984).

Exploration drill programs concentrated on the detection of conductor- and/or fault-related unconformity deposits using the Key Lake model as a basis. Over ten separate drill programs were run in the perimeter zone last winter in the area between Stony Rapids, Key Lake and Wollaston Lake. Minatco Ltd. can earn a 33.3 percent interest in the Wolly Project by spending $23 million on exploration and feasibility studies. The budget for the first phase of this agreement is $5 million over the next four years (Northern Miner, February 21, 1985). The Central Electricity Generating Board Exploration (Canada) Ltd./ Minatco/Uranerz venture will earn an interest in six projects in the area northeast of Key Lake. Denison Mines Ltd. plans to earn an interest in three properties in the southwestern portion of the active perimeter area. Central Electricity Generating Board Exploration (Canada) Ltd., PNC Exploration Canada Ltd. and SMDC have staked the ground which lapsed inside the southwestern part of the Athabasca Basin perimeter area. These new farm-in agreements represent a significant investment. This new money and the high level of technical expertise which the companies bring with them offer a good chance of continued uranium discoveries in the Athabasca perimeter area.

Athabasca Group Interior

The new Cigar Lake Mining Corporation owns a massive uranium deposit close to Waterbury Lake which overshadows other known deposits in the Athabasca Basin. The Cigar Lake Mining Corporation (CLMC) is a new company formed by SMDC (50.75 percent), Idemitsu Uranium Exploration Canada Ltd. (12.875 percent), Cogema Canada Ltd. (32.625 percent) and Corona Grande Exploration Corp. (3.75 percent). The Cigar Lake reserves (SMDC Annual Report 1984) are 110,000 t U at an average grade of 12 percent U. Inferred reserves at the western end of the deposit are 38,000 t U at a grade of about 4 percent U. These figures indicate the Cigar Lake orebody may be double the size of the Key Lake orebody. Consequently, some other known uranium deposits in the Wollaston Lake area (i.e. Dawn Lake and Midwest Lake) which were awaiting development, will likely now be re-examined in relation to this discovery. CLMC will consider the most suitable underground mining method (Northern Miner, June 13, 1985) for the Cigar Lake orebody which lies below Athabasca Group sandstones at an average depth of 430 m. This spectacular discovery, together with improved geophysical methods and the lack of new discoveries in the immediate area of Key Lake, has prompted other comapnies to test basement targets close to 500 m or more below surface.

Exploration methods are the same in the Athabasca Group Interior as in the deeper parts of the perimeter area although exploration is clearly more difficult and costly. Interest in the interior area has increased over previous years, in part due to improved geophysical methods (e.g., large loop UTEM and Pulse EM) which can outline basement conductors at much greater depths. A press release by Imperial Metals Corporation Ltd. on April 22, 1985 reported that hole CLC 5-0011 on the Cogema-operated Close Lake venture south of Blixrud Lake cut 10.18 percent U over 2.5 m (from 641 to 643.5 m). This technical success clearly shows that uranium discoveries can be made in the interior of the basin, while reserves at Cigar Lake prove that these discoveries can be very significant. E and B Explorations Ltd., Saarberg Interplan and Uranerz Exploration and Mining Ltd. have all staked new ground in the interior area. Some of these claim blocks are due west of the Close Lake project and the Read Lake prospect, which was drill tested by Uranerz Exploration and Mining Ltd. this summer.

Carswell Structure

Cluff Lake Mining Ltd., owned jointly by Amok Ltd./Ltée. (80 percent) and SMDC (20 percent) produced 615 t U in 1984 from an underground mining operation on the

Dominique-Peter orebody. Current recoverable reserves are approximately 13,800 t U.

Amok Ltd./Ltée., who have the entire area under disposition in various joint ventures, continue to carry out major surface percussion and diamond drill hole programs. The 1984 exploration program, managed by Amok, found the new Dominique-Janine deposit one kilometer southwest of the Dominique-Peter orebody (SMDC Annual Report 1984). The Dominique-Janine is an area of near-surface or open pit mineralization in basement rocks about 200 m long and 70 m in width. The Carswell Structure uranium finds are unconformity deposits which are usually related to mylonite zones at the contact of the Peter River Gneisses and the Earl River Gneiss Domes (Laine, Alonso and Svab, 1985).

Crystalline Basement

In general, companies have continued to show little interest in the uranium potential of rocks at any distance from the Athabasca Basin, although mineralization is known at some considerable depth below the Athabasca Group unconformity (e.g. the Eagle Point deposit in Collins Bay). Drill programs completed before 1984 indicated geological reserves of 14,600 t U at a grade of 1.6 percent U at Eagle Point North (SMDC Annual Report, 1984).

Platinum Group Elements

Exploration for platinum group elements is new in the province. Lacana Mining Corp. has begun a regional, grassroots exploration program to find platinum group elements in the Peter Lake Domain. The program is based on the idea that the Peter Lake Domain is a layered ultrabasic intrusion cut by later granites. Basic and ultrabasic intrusions in the La Ronge and Rottenstone Domains and the Western Craton also have potential for platinum group elements. In connection with the ERDA Geoscience Program, L. Hulbert of Energy, Mines and Resources Canada is working on the metallogeny of ultramafic and mafic rocks in Manitoba and Saskatchewan (see L. Hulbert, this volume).

Base Metals

Exploration for base metals is limited to joint ventures operated by Granges Exploration AB in the Wapawekka Lake/Oskikebuk River area. Granges drilled extensively in this area last winter. These programs are testing volcanic rocks close to or under the Phanerozoic cover.

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Mineral Exloration Activity in the Reindeer Mining District

by J. G. Pearson

Pearson, J.G. (1985): Mineral exploration activity in the Reindeer Mining district; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The period covered by this report has been one of the most productive in terms of exploration success in many years. All of the major companies that have shown a long term commitment to the area have been successful. Although some of these successes have been in Manitoba (e.g. the Namew Lake discovery by Hudson Bay Exploration and Development Company Limited) they nevertheless point to the largely untapped potential of the southeastern Shield in Saskatchewan. The Geological Survey of Canada's release of Open File 1129 (Gold in Lake Sediments) on May 28, 1985 sparked a significant staking rush, particularly in the east and south Reindeer Lake areas and in a number of other areas where gold had not been previously known.

During the year, 1741.7 km^2 (430,375 acres) were staked in claim blocks and one permit of 155.4 km^2 was taken out. This compares with 1984 figures of 3856.5 km^2 in permits and 411.2 km^2 in claims and claim blocks. During the year 5475.7 km^2 (1,353,099 acres) in permits, claims and claim blocks lapsed.

Gold

Flin Flon Mines Ltd. ceased operations in mid-October 1984 after producing 3770 gm (110 oz.) of gold from 4804 t of ore milled (7529 t mined). Overall recovery was estimated to be 28 percent and the calculated head grade was 2.74 g/t (0.08 oz./ton). Gold recovery and financial problems forced the closure after only 5 months of operation.

Hudson Bay Exploration and Development Company Limited (HBED) carried out a small gold exploration program west of Flin Flon. This program consisted of 1000 m of horizontal loop EM and 474.5 m of drilling in four holes.

The Saskatchewan Mining Development Corporation (SMDC) carried out several gold exploration programs during the past year. The most significant of these resulted in the discovery of a zone of gold mineralization in the Missi Island area of Amisk Lake (Northern Miner, Sept. 16, 1985). Gold and silver mineralization occurs in high-grade veins, and lower grade disseminations and stockworks. First intersected in late 1983 but untested until 1985, the 'Laurel Lake zone' consists of a north-trending high-grade vein system drill-indicated for approximately 125 m along strike and 60 m in depth, and a northwest-trending system of disseminated lower grade mineralization drill-indicated for approximately 150 m along strike and 85 m in depth. Both systems are open in all directions. During the past year SMDC drilled 12 holes to evaluate this mineralization. The joint venture partner in this program is HBED.

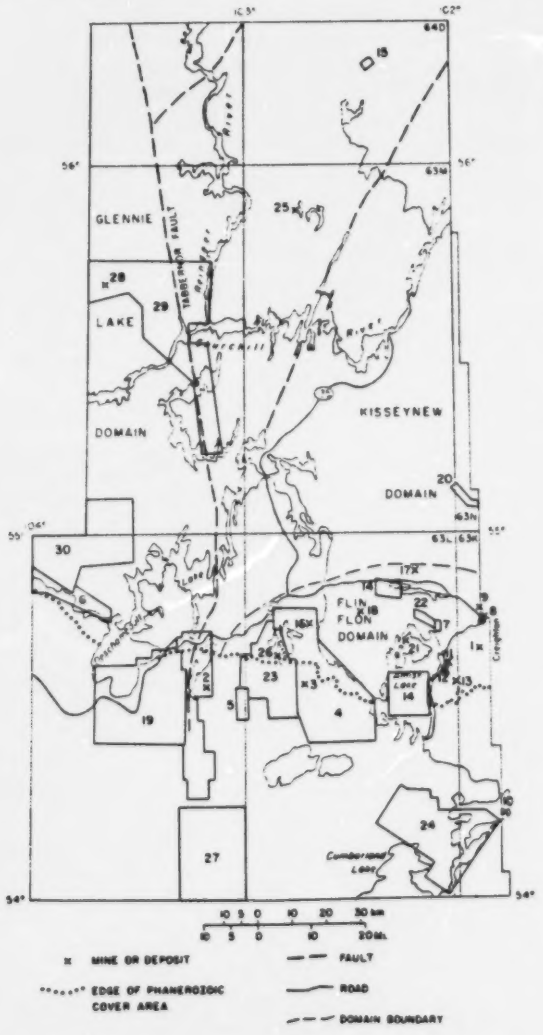

***Figure 1** - Location of the southern part of the Reindeer Mining District showing past and present producing mines, deposits and areas of active exploration. Areas are designated by operator of the project only: Flin Flon Mines Ltd., Rio Mine (1); Granges Exploration AB, Bigstone Deposit (2), McDermott Lake (3), Balsam (4), Chisholm (5), Wapawekka (6), Wolverine (7); Hudson Bay Exploration and Development Co. Ltd., Flin Flon mine (8), Callinan zone (9), Namew Lake deposit (10), Flexar mine (11), Birch Lake mine (12), Coronation mine (13), Amisk Lake - Annabel Lake (14), Kyaska Lake (15), Mal zone (16), Tyrrell Lake zone (17), Fon zone (18); Ice Station Resources (19); Wapa Minerals (20); Saskatchewan Mining Development Corporation, Laurel Lake zone (21), Wolverine (22), Hanson Lake (23), Namew Lake (24); A.L. Parres Ltd., Mokoman Lake zone (25); Western Nuclear Mines Ltd., Hanson Lake mine (26); Cominco Ltd. (27); Placer Development Co. Ltd., Seabee deposit (28); Claude Resources (29); Carina Resources (30).*

In the Missi Island area of Amisk Lake, SMDC drilled eight holes to test previously discovered geophysical and geochemical anomalies in settings similar to that at Laurel Lake. In the Wolverine Lake and East Amisk Lake areas, SMDC carried out gradient array IP, magnetometer, VLF-EM, biogeochemical orientation and reconnaissance lithogeochemical surveys, as well as trenching of several showings.

SMDC also carried out a biogeochemical sampling program to evaluate the potential of the south Phantom Lake area. In the Nesootao Lakes area northwest of Flin Flon, SMDC geologically surveyed horizons which may be correlative with the Tartan Lake deposit of Granges Exploration Ltd. in Manitoba.

Base Metals

Cominco Ltd. continued to explore MPP 1144 and 1151 (which extend from the Squaw Rapids area of the Saskatchewan River to the Marquis Lake area south of Bigstone Lake). Work to date includes 1200 km of airborne EM and magnetometer surveys, and about 60 km of ground EM and magnetometer surveys. Additional geophysical work and possibly diamond-drilling are expected in 1986.

Granges Exploration Ltd. carried out a major drill program on their many properties west of Creighton. At the Bigstone deposit, Granges drilled 1354 m in one hole and four wedges. Ore reserves are estimated to be 1.38 million t grading 2.91 percent Cu and 366,122 t grading 11.2 percent Zn. Other exploration in the Bigstone area included 3470.4 m of drilling in 19 holes to test horizontal loop EM conductors. In a drill program in the McDermott Lake area 56 km west of Creighton, Granges intersected a 6.5 m wide zone grading 3.69 g/t Au, 52.48 g/t Ag, 3.29 percent Cu and 3.3 percent Zn. Follow-up drilling will continue this winter. In the surrounding Balsam Lake permit area, Granges drilled 1081.5 m in 12 holes to test other horizontal loop EM anomalies. In the Wapawekka Lake area, they drilled 2238.9 m in 18 holes to test widely scattered EM anomalies, while in the Wolverine Lake area, four holes totalling 865.2 m were put down, also to test EM anomalies. In the Chisholm Lake area Granges drilled one 54.3 m hole to test an EM anomaly outlined by last year's geophysical program. The company also carried out 224 km of horizontal loop EM, 37 km of VLF-EM and 10 km of magnetometer surveys on these properties.

HBED maintained a very successful exploration program during the past year. In addition to the Namew Lake discovery, HBED discovered another zone of Cu-Zn mineralization (the Callinan Zone) beside the Manitoba-Saskatchewan border 3 km north of Flin Flon. To test this zone HBED drilled 13241.7 m in 38 holes and carried out a 3.1 km magnetometer survey. The following programs were carried out on HBED operated joint venture properties: in the Amisk Lake area, 114.6 km of horizontal loop EM, 110.1 km of magnetometer and 1076.4 m of diamond-drilling in 8 holes; in the Kyaska Lake area, 18.2 km of horizontal loop EM. On wholly owned ground in the Flin Flon and Amisk Lake areas, HBED carried out 95.9 km of magnetometer surveys and 7776 m of drilling in 24 holes. Some of this drilling tested new anomalies, while the remainder explored known zones of mineralization.

SMDC carried out a base metal exploration program in the Hanson Lake area which consisted of 100 km of magnetometer, 40 km of Apex Maxmin EM and 60 km of DeepEM, as well as 1324.4 m of drilling in 11 holes.

SOUTHERN STUDIES

Heavy Oil Reserves of the Bakken Formation, West-Central Saskatchewan

by M.A. Wilson and R.W. Bennett

Wilson, M.A. and Bennett, R.W. (1985): Heavy Oil reserves of the Bakken Formation, west-central Saskatchewan; *in* Summary of Investigations, 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The following is a portion of a study encompassing the total heavy oil reserves within the Lower Cretaceous Series and the Bakken Formation of Saskatchewan. The Bakken Formation is a tripartite unit of shale, sand and shale that is transitional across the Devonian/ Mississippian boundary (Christopher, 1961). The basal shale and middle sand units are laterally consistent, while the thin upper shale unit is rather less consistent, particularly towards the erosional edge of the Bakken Formation (accompanying Maps 1 and 2). For further information on the Bakken see Christopher (1961) and Hornford (1985).

Maps 1 and 2 show the Bakken structure and the Bakken sand isopach respectively. The structure map was constructed using the transition between the top of the Lower Bakken shale and the base of the Middle Bakken sand since this is the most reliable pick on geophysical logs. The high radioactivity of the Bakken shales gives readily identifiable markers when gamma logs are available.

Method

This study was completed using the available geophysical logs for the Bakken Formation within the geographical area enclosing most, if not all, Bakken oil shows (Maps 1 and 2) in western Saskatchewan. The basis for these limits was taken from the maps of Hornford (1985).

The constraints applied in defining the pay zones were as follows:

1) Presence of oil - This was determined using the Resistivity logs with a minimum value of 7.5 ohm-metres being necessary in areas of approximately 11^0 to 16^0 API gravity oil and 10 ohm-metres where the API

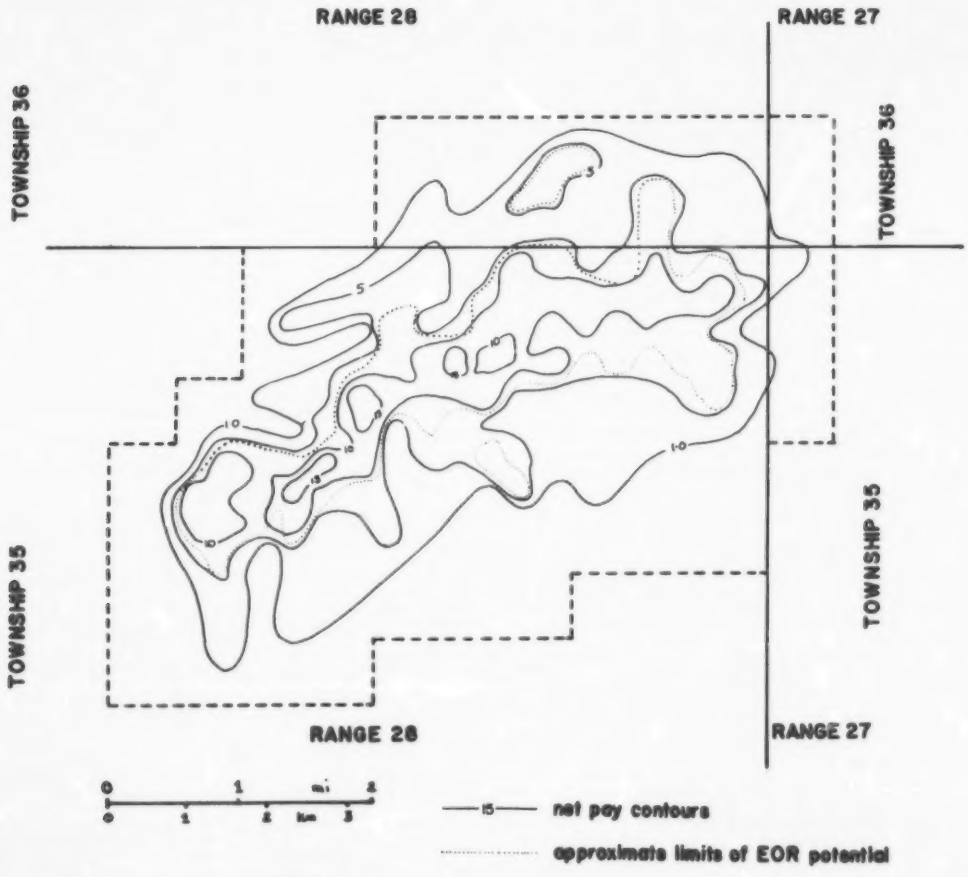

Figure 1 - Net pay and potential EOR area, Cactus Lake pool (marked as C on Map 1).

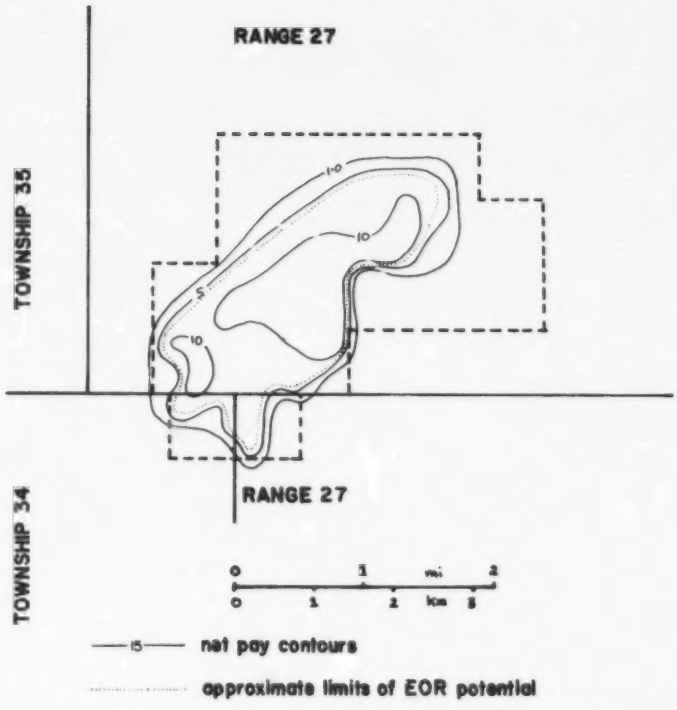

Figure 2 *- Net pay and potential EOR area, Plover Lake pool (marked as D on Map 1).*

gravity of the oil fell below 11°. (The assumption was made that gravity and viscosity are related).

2) Porosity - A minimum of 24 percent porosity was considered necessary and taken from the density-porosity curve on the Compensated Density - Compensated Neutron Log.

3) Water Saturation - A maximum of 50 percent water saturation was used. This was calculated using the Rwa and Fr/Fs comparison method where the logs indicated that the oil saturation in the well might be too low.

4) Thickness - A minimum of 1 m of oil pay was deemed necessary for economic oil production.

In many cases value judgements had to be made where complete geophysical log suites were unavailable. Only electric logs were taken for many of the older wells, so only resistivity cut-offs could be used. Here it is not always possible to determine cemented zones against oil-filled sands or some gas-filled sands.

Once these cut-off values had been assigned, the only exceptions made involved those few situations where oil is being produced but the cut-off limits, as read from the geophysical logs, were outside the defined range.

The oil pay map (accompanying Map 1) shows the oil distribution for the Bakken Formation. Individual wells are shown as oil shows only. When calculations were made, these shows were assumed to cover an area of 16.2 ha (40 acres), the usual drainage area for heavy oil wells. The thickness of oil pay in the well was assumed to be the same throughout the 16.2 ha for the convenience of calculation. It is understood that in most cases the oil would extend over an area greater than 16.2 ha and that pay thickness would vary; these variations will tend to cancel each other out, resulting in moderately realistic oil-in-place figures.

Where wells are grouped, and the structure map indicates that the wells are related, an attempt was made to link the wells by contouring the pays and calculating the oil in place as a small pool. These calculations, and the calculations for some pools, were based on a map scale of 1:126,720 (1 inch to 2 miles) using a 10-acre grid pattern. For the pool areas, with potential pool extensions, a larger scale of map was used. Again, a grid of 10 acres (occasionally less) was superimposed to calculate the area.

Where the oil shows could be contoured, the outer limit was taken as the 1 m contour (net pay) line. This line, where possible, was based on structure contours. The use of a 10 m contour interval on the structure map (Map 1) precludes the definition of fine structural detail, as does the wide scatter of points outside pool boundaries, with

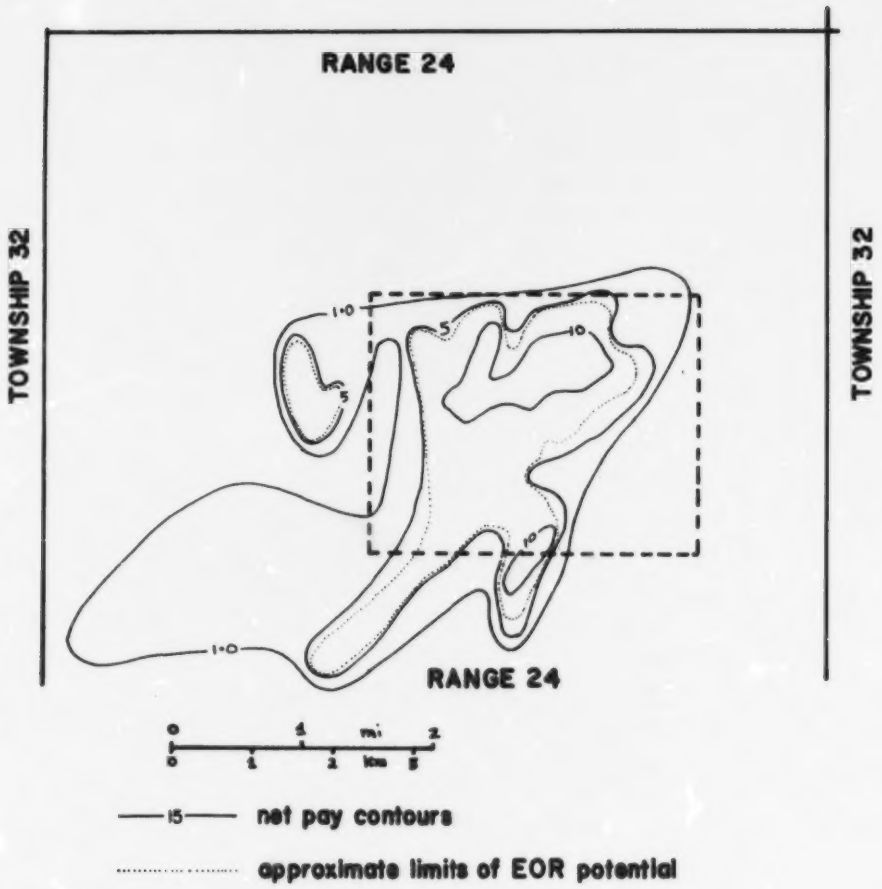

Figure 3 *- Net pay and potential EOR area, Buffalo Coulee pool (marked as G on Map 1).*

the result that the outer oil limit is rather subjective. Subsequent contours, at 5, 10 and 15 m, can be considered as more accurate in most cases. It should be noted here that net pays may be composed of multiple pay zones within the Bakken sand. These multiple pays were simply added together for construction of the oil-in-place maps. With the contours constructed and the areas summed, the pay for the area was calculated using the average for the contour interval (i.e., 1 m to 5 m averaged at 3 m, 5 m to 10 m averaged at 7.5 m, etc.). If the upper limit was well below the next contour interval (i.e., 12.8 m), then this upper figure was taken as the limit and averaged (i.e., 12.8 m - 10 m = 2.8 m, average this at 1.4 m giving an average of 11.4 m for this area).

The figures of oil-in-place were then calculated using average net pay, area, average porosity, average water saturation, and shrinkage factor. For the purpose of calculating oil in place for the isolated wells, an average of porosity, water saturation and shrinkage factor for the Bakken pools was used.

The figures are given as cubic metres of oil at the surface, with the equivalent in barrels given in some cases. The conversion factor from m^3 to barrels was taken, again as an average, as 6.4 (Levorsen, 1954).

Results

Individual calculations are available from the authors. The generalized total calculations are given in Table 1. In imperial terms, the Bakken reserves of oil-in-place are in excess of 1.5 billion barrels. With an assumed recovery rate of 5 percent, this translates to almost 80 million barrels of recoverable oil (12.26×10^6 m^3 or 12.26 million cubic metres).

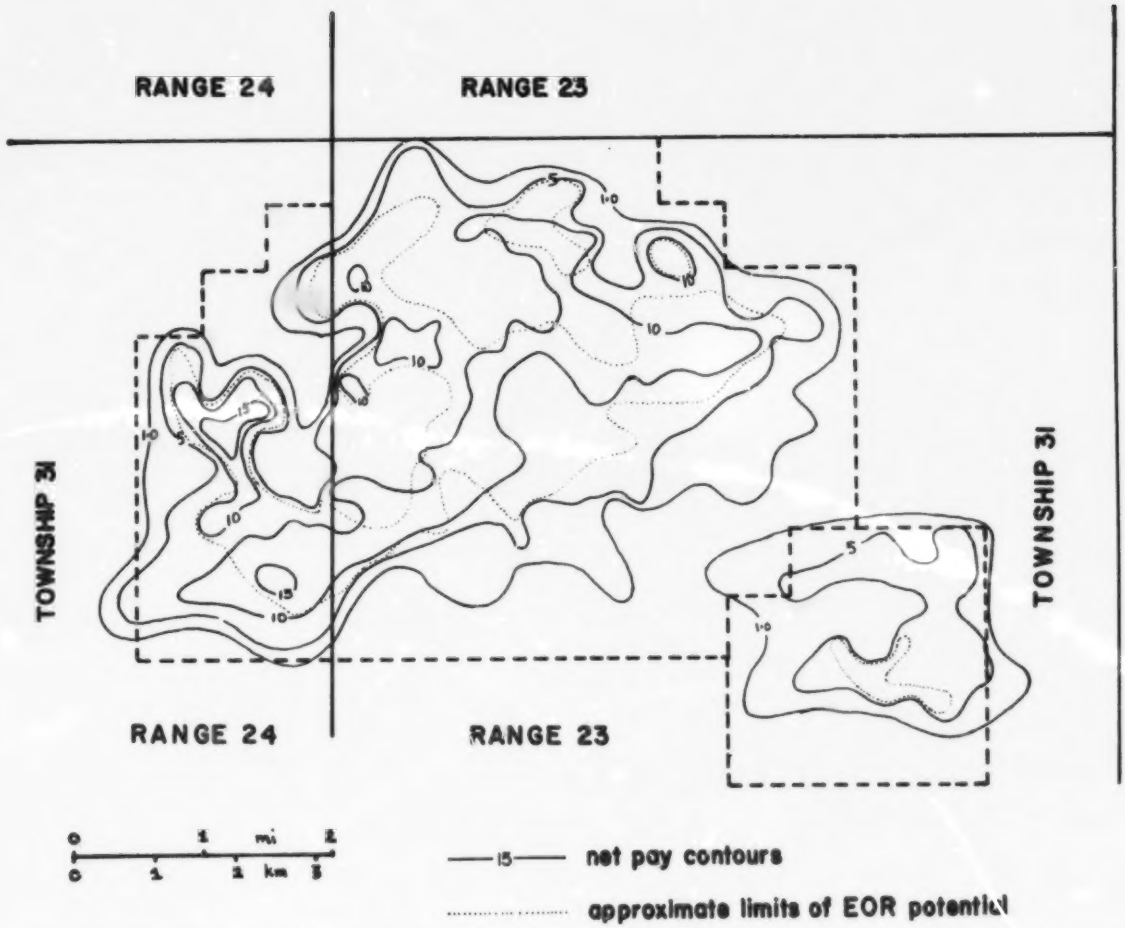

***Figure 4** - Net pay and potential EOR area, Coleville and Coleville South pools (marked as H and I, respectively, on Map 1).*

Table 1 - Reserves of Oil-in-Place

	Oil-in-Place		ϕ	$1\text{-}S_w$	SF
	m^3 ($x10^4$)	barrels ($x10^4$)			
Miscellaneous oil in place	4510.97	28870.2	0.285	0.75	0.95
Fusilier	551.65		0.254	0.78	0.938
North Hoosier	1922.5		0.305	0.78	0.95
Hoosier	1065.94		0.315	0.78	0.928
Coleville South	554.27		0.241	0.69	0.928
Coleville	3507.82		0.241	0.69	0.928
Buffalo Coulee and potential extension	1674.91		0.23	0.75	0.90
Buffalo Coulee North and potential extension	2304.97		0.295	0.75	0.93
Cactus Lake	3432.82		0.294	0.75	0.95
Court	1210.91		0.285	0.75	0.95
Hearts Hill	660.4		0.285	0.75	0.95
Luseland	1828.66		0.285	0.75	0.95
Plover Lake	1334.51		0.315	0.75	0.95
Total for Pools and Pool extensions	20049.36	128315.90			
Overall Bakken total	24560.33	157186.11			

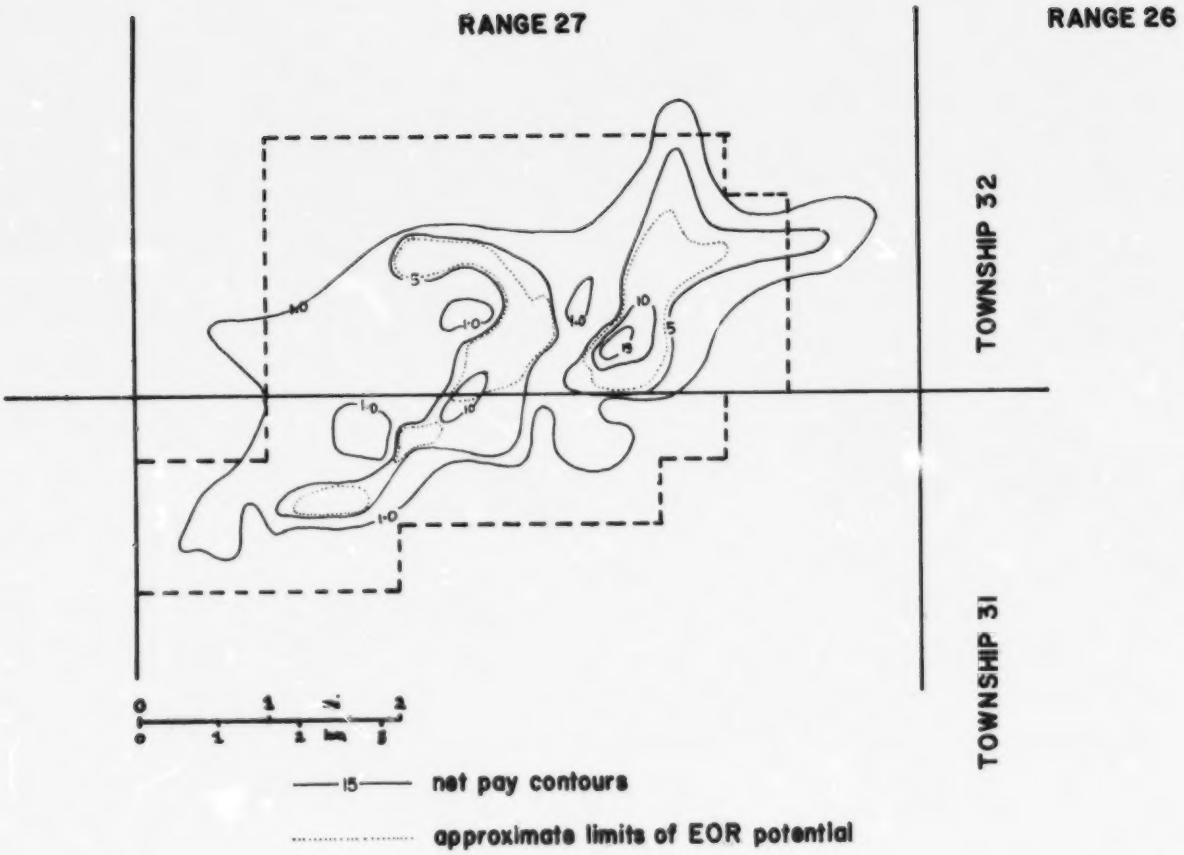

Figure 5 - Net pay and potential EOR area, North Hoosier pool (marked as K on Map 1).

Table 2 - Reserves with Enhanced Oil Recovery Potential

	m^3 (x 10^4)	barrels (x 10^4)
Fusilier	139.14	890.47
North Hoosier	718.18	4596.33
Hoosier	252.5	1616
Coleville South	64.27	411.33
Coleville	1695.91	10853.84
Buffalo Coulee	1086.14	6951.27
Buffalo Coulee North	532.44	3407.62
Cactus Lake	1221.51	7817.69
Court	870.28	5569.8
Hearts Hill	48.81	312.41
Luseland	1217.16	7789.82
Plover Lake	1083.55	6934.75
Miscellaneous	1221.27	7816.11
Total	10151.16	64967.42

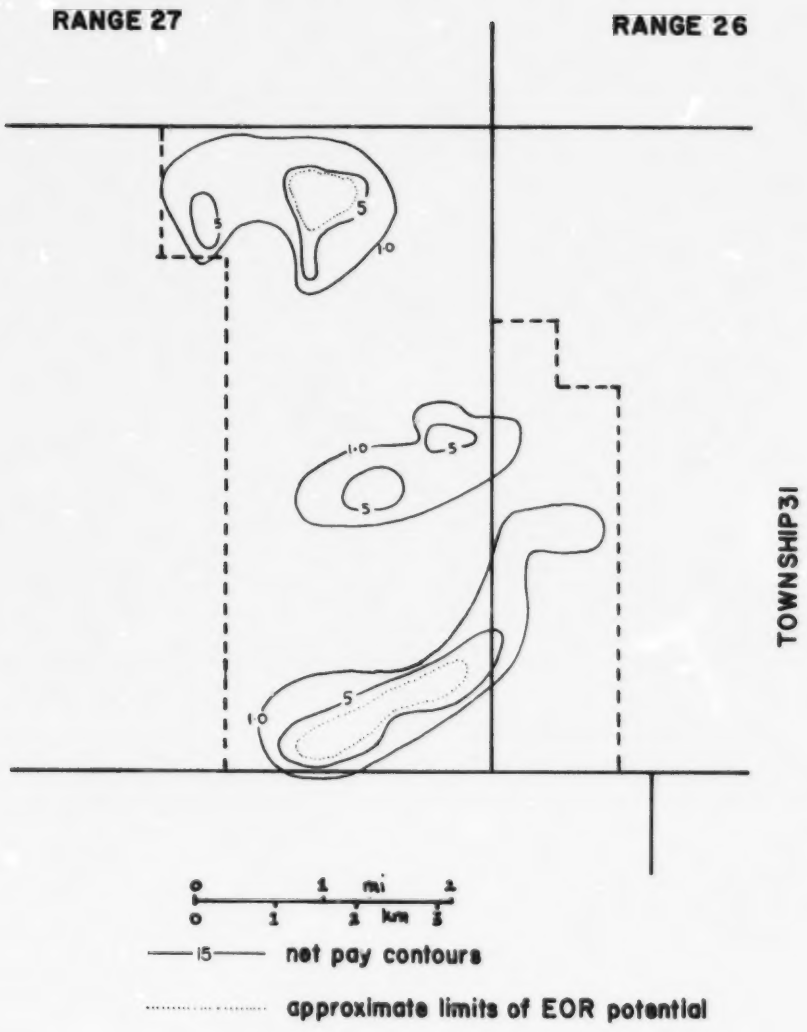

Figure 6 *- Net pay and potential EOR area, Hoosier pool (marked as L on Map 1).*

In addition to total oil-in-place, the figure for oil with E.O.R. (Enhanced Oil Recovery) potential was also calculated (Table 2). A basic minimum thickness of 6 m in a single pay zone was taken to provide the limits. It must be noted that this ignores both gas cap and bottom water. The figures use the same base as the total oil-in-place calculations.

This total for oil with EOR potential accounts for approximately 41 percent of the oil-in-place in the Bakken Formation.

The approximate limits for oil with EOR potential are shown on Map 1 and Figs. 3 to 8.

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Notes on the Jurassic-Cretaceous Petroleum-Producing Zones in the Wapella-Moosomin Area, Southeastern Saskatchewan

by L.K. Kreis

Kreis, L.K. (1985): Notes on the Jurassic-Cretaceous petroleum-producing zones in the Wapella-Moosomin area; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-4.

The petroleum possibilities of the Wapella area were discussed in an unpublished internal report by Hutt and Schmid (1964). Well information collected since then is used in this report to upgrade their structure contour maps in the Wapella field and produce several new cross-sections in the Wapella area. In addition, stratigraphically related recent (1984) discoveries in the Moosomin and Red Jacket areas are compared. The relevant areas are shown in Fig. 1. A comprehensive bibliography is included.

Well Information

Subsequent to the study by Hutt and Schmid (February, 1964), 81 new wells have been drilled (26 field and 55 wildcat) as of January 1, 1985. This gives a grand total of 145 wells in their study area (Fig. 1).

Ten of these new wells have core over at least some of the zone of interest (Jurassic-Cretaceous). This gives a sum total of 51 cores in their study area as of January 1, 1985.

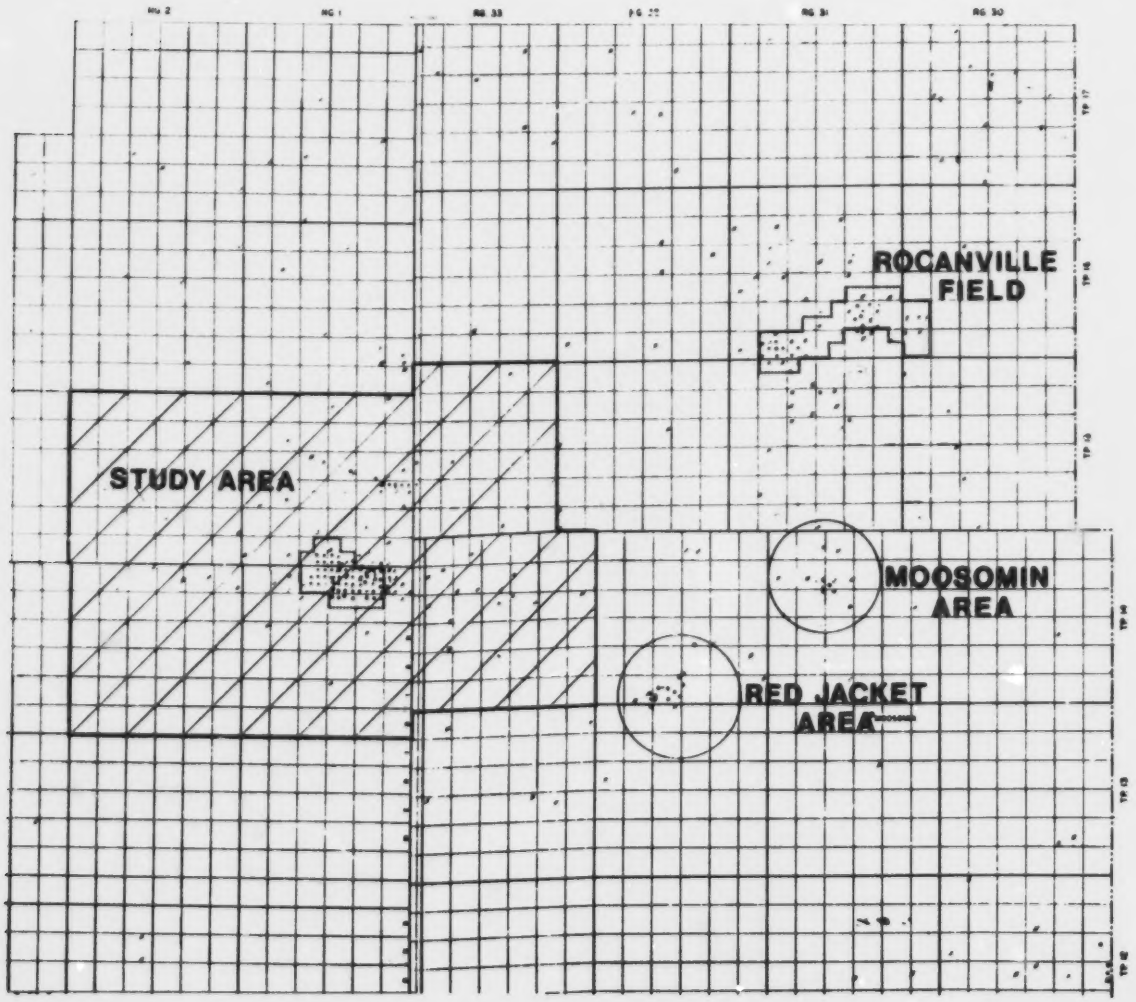

***Figure 1** - Location map.*

Generally, these newer holes have much better core recovery than was attainable from the earlier wireline types. Most of the cores are located at or near the known producing zones, especially those within the pool boundaries where producing zones are better defined. They also tend to be less than 20 m long, a fact which limits their usefulness to relatively short Jurassic or Cretaceous intervals.

Producing Zones

Hutt and Schmid (1964) listed five producing zones. These were, in descending stratigraphic order, the Upper Blairmore, Wapella Sand, 16-33, 15-34 and 4-3 zones. The producing zone in the Upper Blairmore (now termed the Upper Mannville) was not adequately defined. As it was only present in one well, the Imperial-Tidewater Wapella No. 6-33-14-1, it is hereby named the 6-33 zone, following Hutt and Schmid's naming convention. Their relative positions are shown in Fig. 2, CNW Wapella 10-35, though it must be noted that no one well in the area produces from all five zones. Recent drilling has discovered two additional producers in the equivalent of the 6-33 zone in the Wapella field (10-35-14-1W2 and 8-35-14-1W2). Cross-section D-D' (Fig. 14) shows the producing zone in these wells.

A miscellaneous basal Mannville(?) producer 7-17-15-1W2 (Figs. 3 and 4) was discovered in 1984. This zone is here

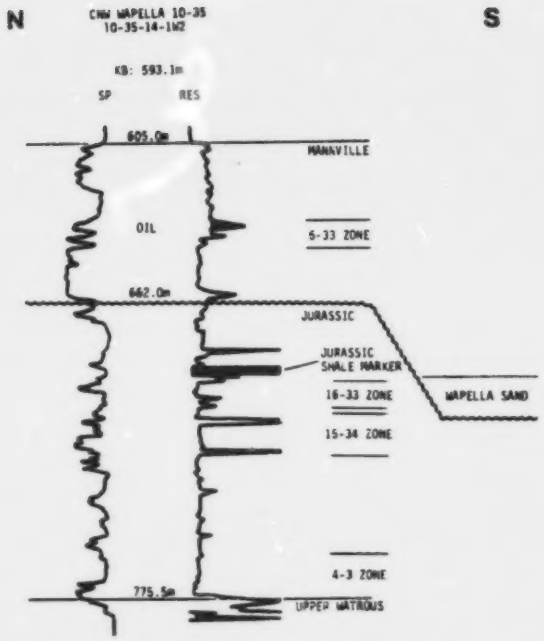

Figure 2 - Geophysical log section showing relative positions of petroleum-producing zones in the Wapella area.

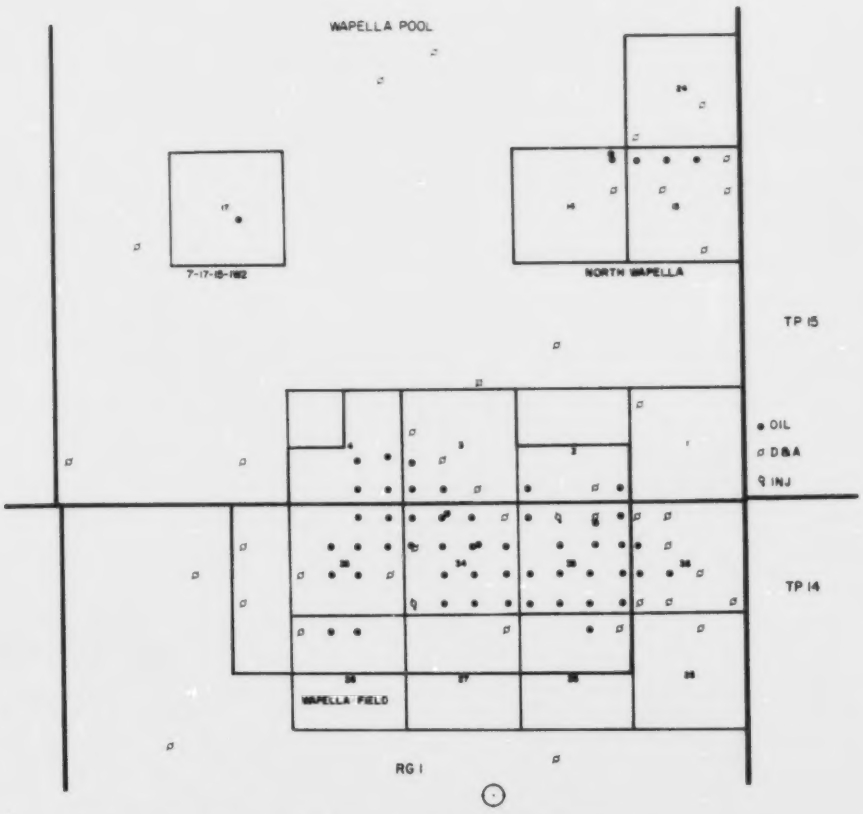

Figure 3 - Detailed location map showing well status, Wapella area.

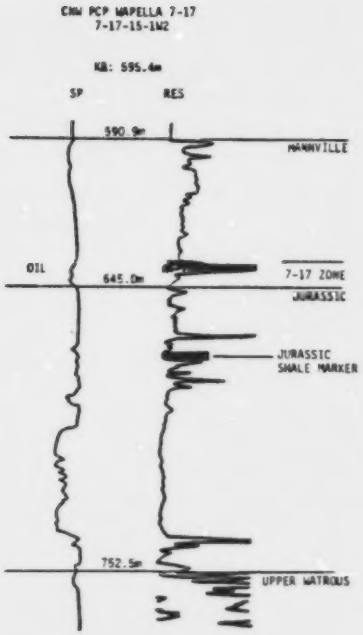

Figure 4 - *Geophysical log section showing basal Mannville producing zone.*

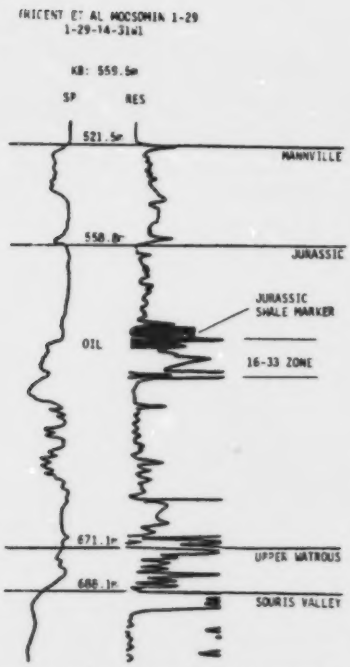

Figure 5 - *Geophysical log section showing 16-33 zone (Jurassic) in the Moosomin discovery well (1-29-14-31W1).*

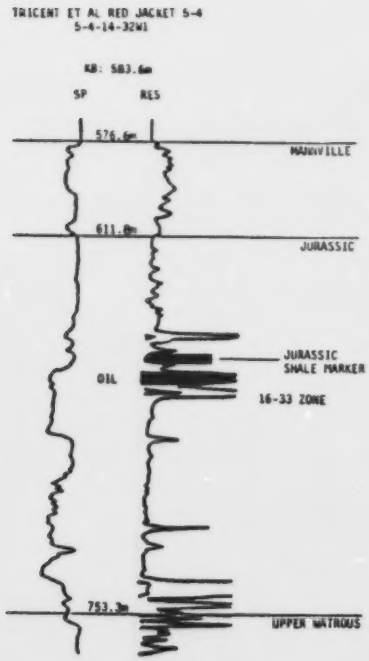

Figure 6 - *Geophysical log section showing 16-33 zone (Jurassic) in the Red Jacket discovery well (5-4-14-32W1).*

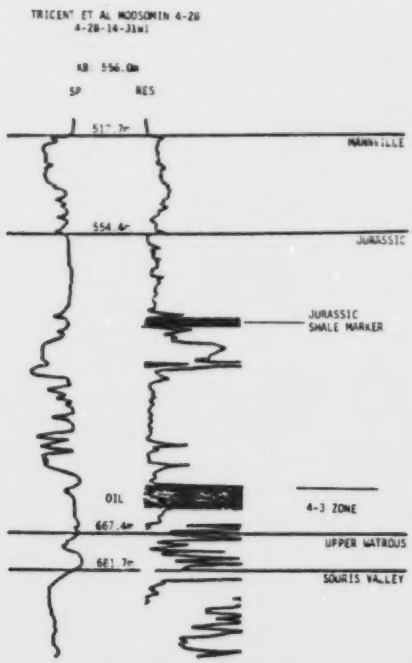

Figure 7 - *Geophysical log section showing 4-3 zone (Jurassic) in the Moosomin discovery well 4-28-14-31W1.*

designated the 7-17 zone. It is probably correlative with the 6-33 zone described above.

The majority of the increase in oil production in the study area comes from several zones in the Jurassic, such as are found in the wells in section 36 of township 14. Some miscellaneous Jurassic production just outside the Wapella Field boundary and production from the 16-33 zone in the North Wapella area (Figs. 2, 3 and 15) have also contributed. Fig. 3 shows the well status in the oil-producing portion of the study area on January 1, 1985.

New discoveries in the Moosomin and Red Jacket localities (Fig. 1) appear to be producing from two of the zones discussed above. In particular, the 16-33 zone, which occurs just below the Jurassic shale marker as in the Wapella Field and North Wapella area, is a producing zone at both Moosomin and Red Jacket (Figs. 5 and 6). In addition, new production from what appears to be the equivalent of the 4-3 zone in the Wapella area is found in the Moosomin locality. The first production of this zone came from the 4-28-14-31W1 well, which was off-confidential as of May 18, 1985 (Fig. 7).

Structure and Stratigraphic Correlation

The post-1964 data support the conclusion of Hutt and Schmid (1964) that the key to Wapella Sand deposition was the existence of an east-trending ridge, 30 m or more in height, through the Wapella Field (Fig. 8). However, correlations of the Wapella Sand employing new wells in the eastern half of the field are less certain. See Fig. 9 for the locations of these and other cross-sections.

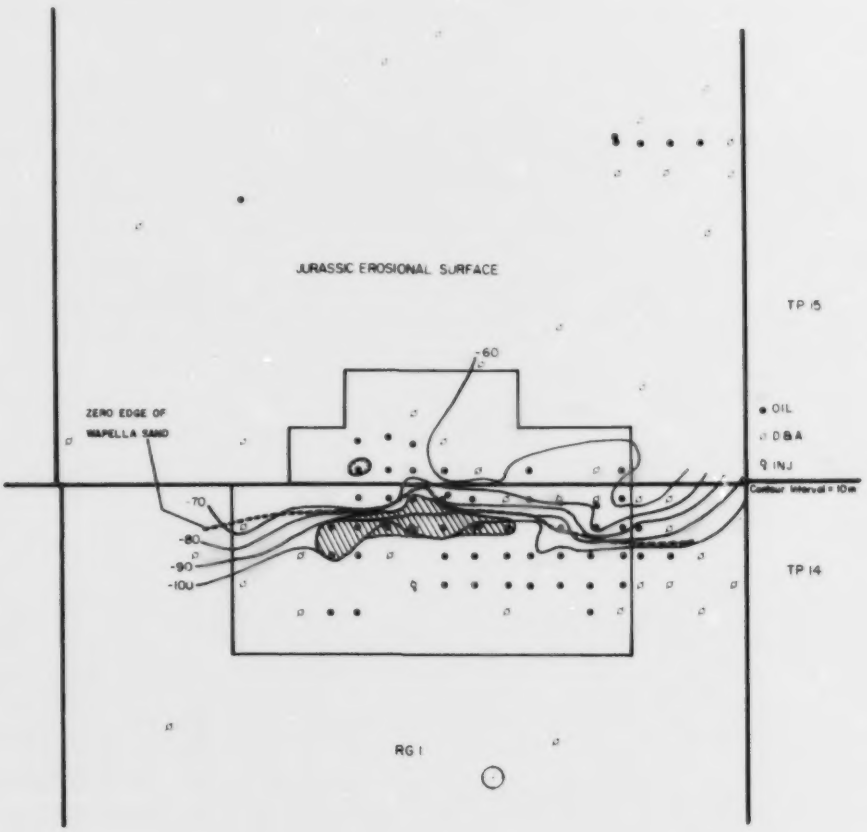

***Figure 8** - Structure contour map on the Jurassic erosional surface, Wapella area.*

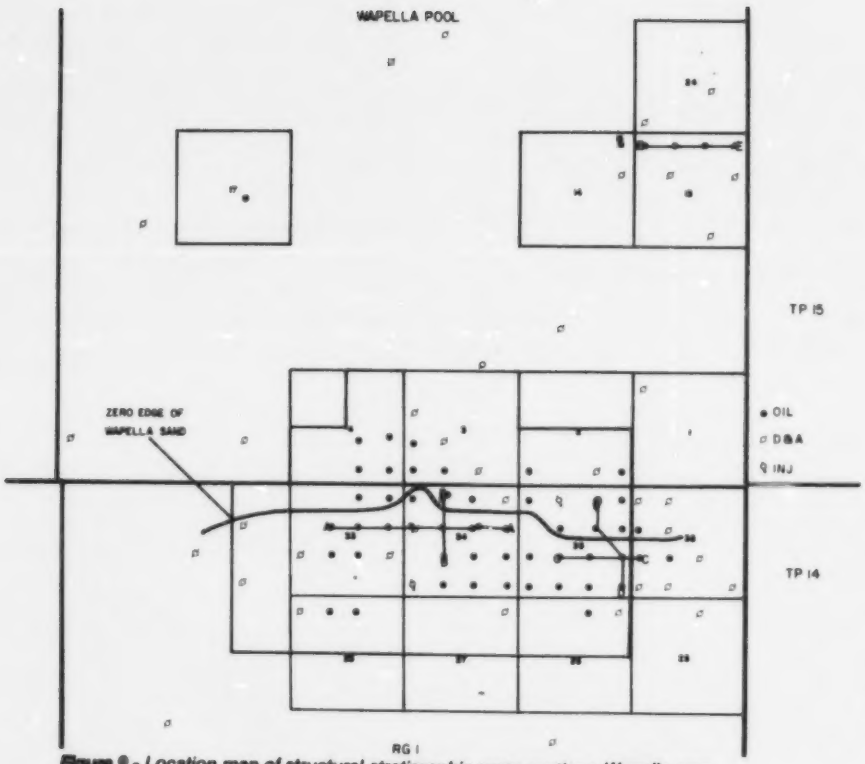

Figure 9 - *Location map of structural-stratigraphic cross-sections, Wapella area.*

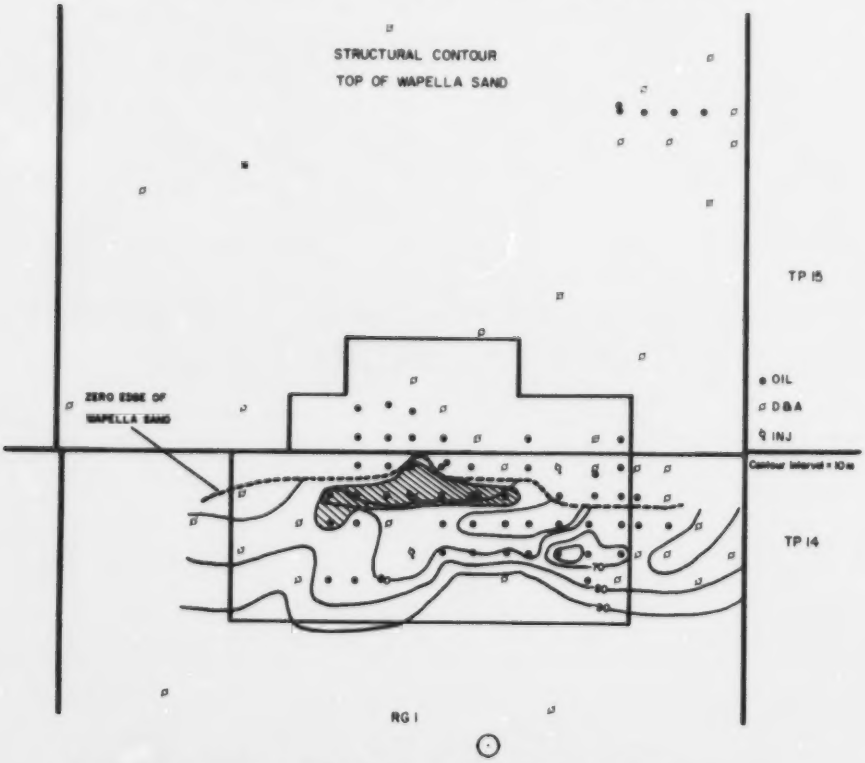

Figure 10 - *Structure contour map on the top of Wapella Sand, Wapella area.*

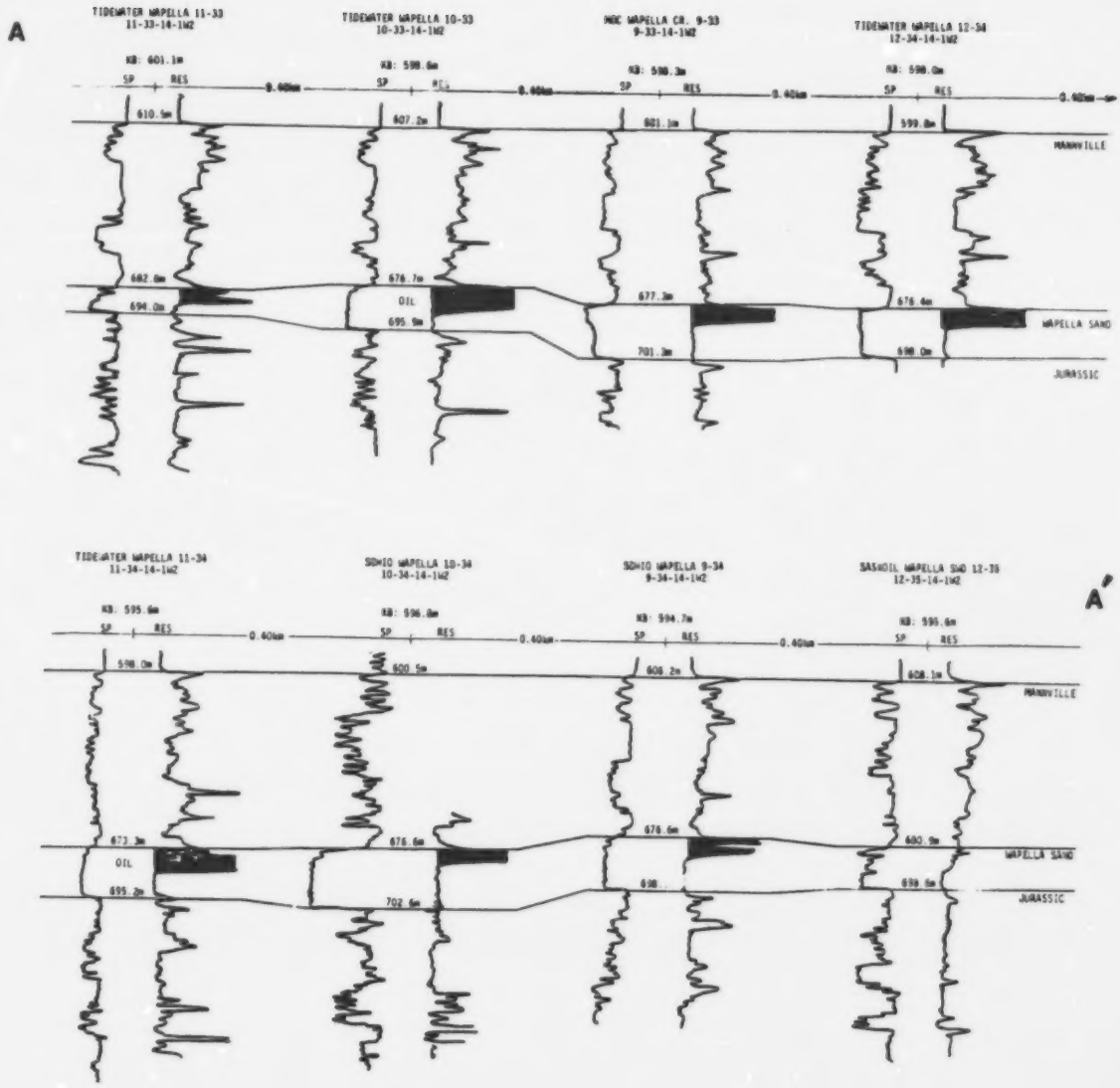

Figure 11 *- Structural-stratigraphic cross-section A-A'.*

Section A-A' (Fig. 11) is an east-west cross-section through an area of the field where the Wapella Sand was originally described and has proven to be productive. Section B-B' (Fig. 12) is a north-south cross-section through the same productive Wapella Sand reservoir. These two sections appear to be accurate in their correlation of Wapella Sand. The area shaded in Figs. 8 and 10 shows where the Wapella Sand is productive.

However, correlation further east is suspect because the shaly interval above the Wapella Sand in the west becomes silty or sandy in the east, thereby coalescing with sandy intervals above and forming one continuous sandy zone. This makes it difficult to recognize the continuity of the Wapella Sand as a separate entity in cross-sections constructed purely from geophysical logs. Section C-C' (Fig. 13) is an east-west section while D-D' (Fig. 14) is a north-south section in the area east of where the Wapella Sand is productive. The structure contours on the top of the Wapella Sand in this part of the Wapella Field (Fig. 10) are similarly suspect.

No detailed geological study of the area has been done, and such a study was beyond the scope of this report. However, the recent Jurassic discoveries in the Moosomin and Red Jacket areas show the region to have greater production potential than previously believed and a detailed study could prove rewarding.

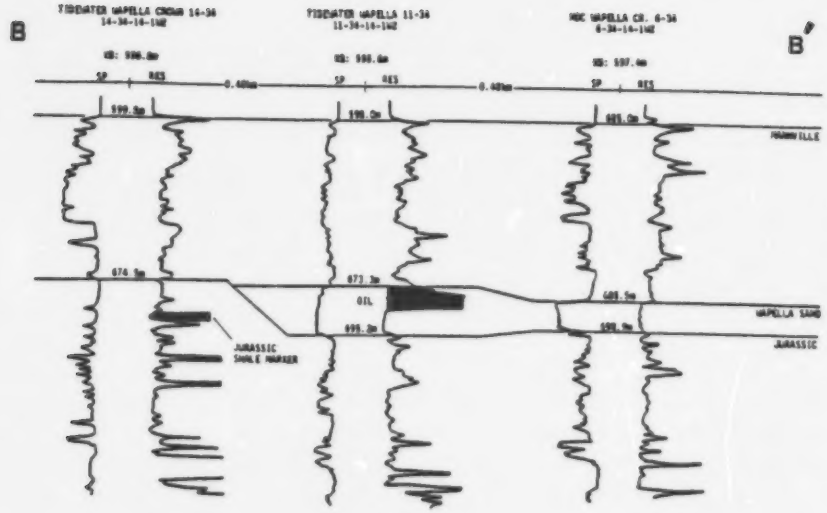

Figure 12 *- Structural-stratigraphic cross-section B-B'.*

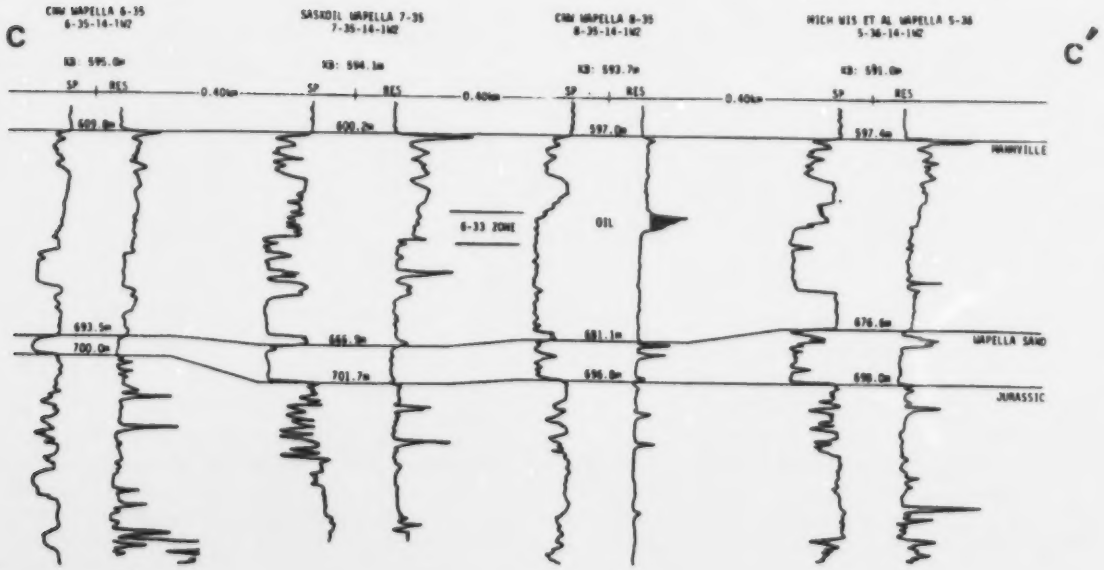

Figure 13 *- Structural-stratigraphic cross-section C-C'.*

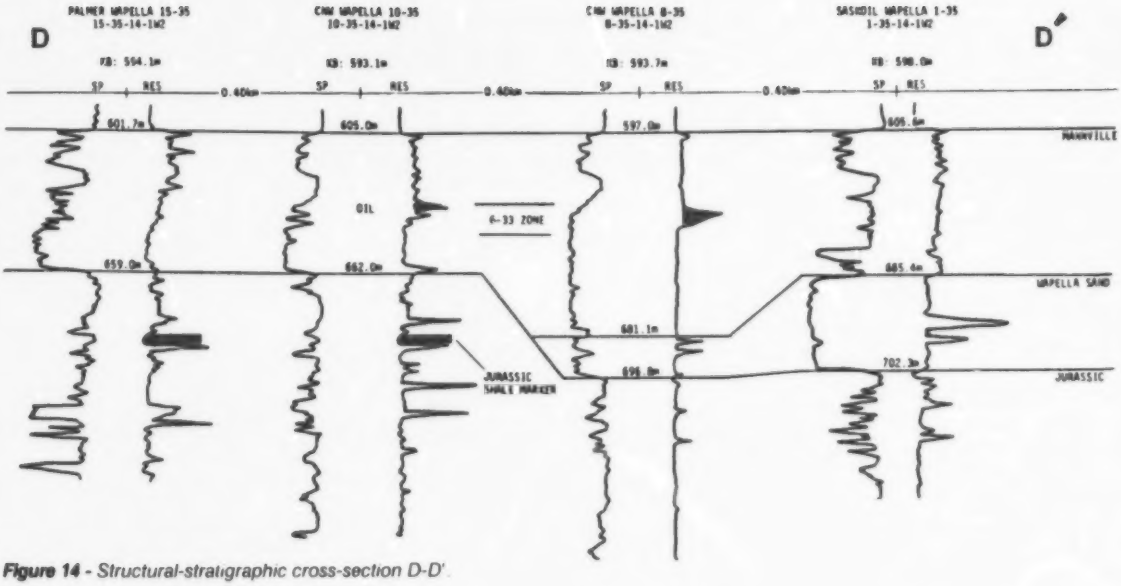

Figure 14 *- Structural-stratigraphic cross-section D-D'.*

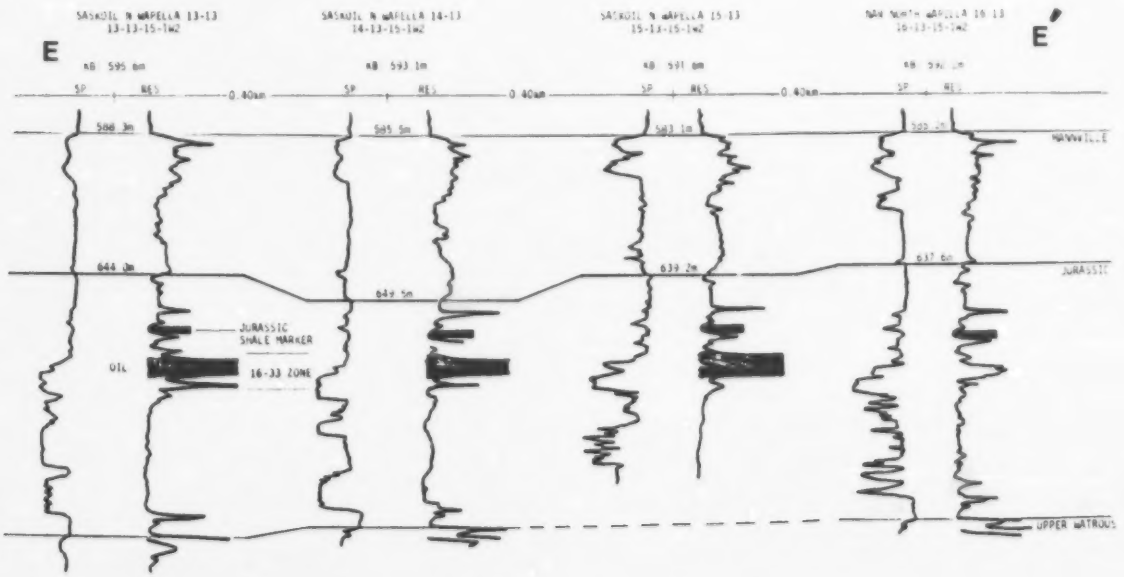

Figure 15 *- Structural-stratigraphic cross-section E-E'.*

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Project 8526

The Precambrian of Central and Southern Saskatchewan: Correlations with Lithotectonic Elements in the Southwestern Trans-Hudson Orogen

by Kenneth D. Collerson[1] and John F. Lewry[1]

Collerson, K.D. and Lewry, J.F. (1985): The Precambrian of central and southern Saskatchewan: correlations with lithotectonic elements in the southwestern Trans-Hudson Orogen; *in* Summary of Investigations 1985, Saskatchewan Geological Survey; Saskatchewan Energy and Mines, Miscellaneous Report 85-5.

The almost entirely unexposed 'Dakota Segment' of the Trans-Hudson Orogen extends southwards from the exposed Precambrian Shield through central and southern Saskatchewan into Montana and the Dakotas. An understanding of the geological evolution of this segment is of critical importance in developing models of the Early Proterozoic evolution of the North American Craton. Previous petrological and geochemical studies of basement specimens recovered from drill core in this region have been carried out by King (1966), Burwash and Culbert (1976), Burwash and Cumming (1974), Burwash and Krupicka (1969, 1970), Burwash et al., (1962, 1973), Rosholt et al., (1970), Peterman and Hedge (1964), and Peterman and Goldich (1982).

We are currently re-examining forty-six basement core samples from central and southern Saskatchewan in order to interpret them in the context of established lithotectonic elements of the exposed Shield to the north (Lewry, 1984; Lewry et al., 1985) and of available subsurface geophysical data (Dutch, 1983; Arvidson et al., 1984; Green et al., 1985a, b). A pilot Sm-Nd isotopic study of selected core samples will provide model age information regarding the timing of separation of the protoliths of these rocks from their mantle source regions. In conjunction with U-Pb zircon age data from the University of Kansas, the Nd isotopic data will yield information concerning the isotopic character of these source regions and the nature of crust formation processes. This study will complement crust formational studies based on Nd isotopic data in 1) the exposed portion of the Trans-Hudson Orogen in northern Saskatchewan (Chauvel et al., in press; Collerson and Lewry, this volume), 2) the basement of the western Canadian sedimentary basin in Alberta and southern British Columbia (Frost and O'Nions, 1984) and 3) the concealed mid-continental region of the North American Craton (Nelson and DePaolo, 1985).

Petrology and Metamorphic Grade

In order to select samples for isotopic analysis, polished thin sections of cored basement lithologies were examined to assess their degree of alteration, rock type and metamorphic grade. This was to determine whether or not there are clear correlations with known lithotectonic elements in the exposed portion of the shield and whether postulated southward extrapolation could be made based on geophysical interpretation. Exposed domains in the north are lithologically extremely diverse and complicated, and in view of the limited number of data points, clear-cut correlations are difficult to establish. Nevertheless, several interesting features were identified. These are discussed below in terms of a broad geographic subdivision for the unexposed basement.

(1) Northwestern Area

Core from this area includes one orthopyroxene-hornblende-bearing quartzofeldspathic gneiss, several granulite facies garnet-cordierite-sillimanite-potassium feldspar-bearing pelitic gneisses and an augen granitic gneiss. The overall lithological assemblage and indicated metamorphic grade are consistent with that typical of much of the exposed Cree Lake Zone and with extrapolations of this zone to the south and southwest.

(2) Southwestern Area

Basement lithologies in this part of the province include amphibolite facies hornblende-bearing tonalitic gneisses, a massive orthoquartzite, and a variety of undeformed rapikivi granites and possible felsic volcanics. The age and metamorphic grade of the quartzite are equivocal; however, the presence of traces of diopside and the nature of recrystallized microstructures suggest possible amphibolite facies metamorphic conditions. The unit could represent an Early Proterozoic shelf sequence, comparable with either the Snowy Pass Supergroup of the Medicine Bow Mountains in southeast Wyoming or parts of the Wollaston Group.

The most significant and unexpected lithologies occurring in the southwest are two rapikivi granites containing large compositionally zoned K-feldspar megacrysts, and three porphyritic rhyolites, considered to be high-level intrusives or extrusives. Ferrohastingsite appears in both granites and rhyolites. Previously published U-Th-Pb geochronological data for one of the granites in this suite indicates a crystallization age of c. 1790 Ma (Rosholt et al., 1970). The suite is tentatively correlated with post-Hudsonian anorogenic magmatism of the Dubawnt

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Project contracted to the University of Regina with funds provided under the Saskatchewan component of the Canada-Saskatchewan Subsidiary Agreement on Mineral Development 1984-89.

Phases of this research were also supported by NSERC grants A0594 to K.D.C. and A7426 to J.F.L.

Group in the Thelon Segment of the Orogen (Donaldson, 1965; Blake, 1980) and provides an important constraint on timing of tectonothermal activity in this part of the Orogen. Specimen distribution suggests that a major area of anorogenic plutonic and volcanic activity extends from Swift Current south to the U.S. border. Significantly, this 'Swift Current Anorogenic Province' lies on the northeasterly extension of the Great Falls Tectonic Zone (O'Neill and Lopez, 1985) which has been the locus of igneous activity and recurrent fault movements from early or mid-Proterozoic time through to the Holocene. It is also in the vicinity of the postulated northeastern margin of the Archean Wyoming cratonic province.

(3) South-Central Area

Cores from the Regina - Moose Jaw area comprise weakly to moderately foliated, locally garnetiferous megacrystic and non-megacrystic granites, similar to lithologies that form much of the Wathaman Batholith. One hole immediately south of the exposed shield intersects similar material, which in this case is almost certainly an extension of the batholith.

Farther east, both in the north and south, lithologies comprise tonalitic and granodioritic gneisses, medium- to high-grade supracrustal rocks and a variety of non-diagnostic pink granite and granodiorite. This change in lithological assemblage, similar to that occurring east of the exposed Wathaman Batholith, roughly coincides with the estimated position of the North American Central Plains Conductivity Anomaly (Camfield and Gough, 1977).

(4) Southeastern Area

Basement core in the southeast includes upper amphibolite to granulite facies tonalitic and granitic orthogneisses, as well as pelitic and mafic gneisses which reflect the presence of supracrustal sequences. There is no clear correlation with geophysical boundaries and subdivisions. Two cores from North Dakota, immediately south of the Saskatchewan - United States border contain zircons which yield U-Pb discordia intercept ages of c. 2900 Ma, with lower intercepts of c. 1650-1750 Ma (Peterman and Goldich, 1982). Potassium feldspar-cordierite-biotite gneiss (from Imperial Stoughton 3-27) in southeastern Saskatchewan gives a Sr model of age of c. 2500 Ma (Peterman and Hedge, 1964). These data indicate that the Archean Superior Province extends further west than has been previously thought on the basis of geophysical data. Within the relatively narrow 200-300 km wide zone between the previously known western limit of Archean rocks in the Superior Province and the possible Wathaman extension, there is clear evidence of an Archean crustal component which was probably variably effected by Hudsonian thermo-tectonism. Late Hudsonian evolution in the Dakota Segment of the Trans-Hudson Orogen probably involved transcurrent movement in which the arc terrains in the north were dismembered and obliterated (cf. Green et al., 1985a, b).

(5) North-central and Northeastern Area

In the north-central northeastern part of the unexposed shield, unretrogressed granulite facies ortho- and paragneisses are identified. These lie west of both a blastomylonitic zone tentatively related to the Churchill-Superior boundary zone and the geophysically exposed subsurface extension of the Tabbernor fault zone. One extremely fresh intermediate granulite has yielded abundant zircon which lies on concordia at c. 1784 Ma (Bickford, pers comm., 1985). These high-grade rocks lie to the south of low-grade parts of the exposed Glennie Lake Domain, and their significance is currently unclear.

To the west of this high-grade area, metamorphic grade decreases abruptly in the Choiceland area, where several holes intersect a low-grade metasedimentary assemblage which includes thick sequences of banded iron formation. The relation between the low- and high-grade area is obscure.

Nd Isotopic Analysis

Six samples, representing the freshest of the main basement lithologies, have been selected for Nd isotopic analysis. Splits have also been sent to the University of Kansas for zircon separation. This material comprises:

1) 8-30-8-33W1 - hornblende-biotite-bearing tonalitic gneiss, southeast Saskatchewan.
2) 3-8-17-19W2 - garnetiferous megacrystic granite, Regina.
3) 2-21-16-17W3 - biotite-bearing granite, Swift Current Anorogenic Province; sample dated by Rosholt et., (1970).
4) 9-22-45-12W2 - intermediate granulite facies gneiss, east-central Saskatchewan.
5) 7-14-56-17W3 - charnockite, northwest Saskatchewan.
6) 8-8-64-2W3 - biotite-bearing tonalitic gneiss, central Saskatchewan.

Results and interpretation will be presented in a subsequent report.

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ABSTRACTS OF RECENT SASKATCHEWAN ENERGY AND MINES PUBLICATIONS

Christopher, J.E. (1984): Depositional patterns and oilfield trends in the Lower Mesozoic of the northern Williston Basin, Canada; *in* Oil and Gas in Saskatchewan, edited by J.A. Lorsong and M.A. Wilson; Saskatchewan Geological Society, Special Publication 7, p83-102.

The Early Mesozoic depositional setting of the Williston Basin went through several phases following termination of the vast Paleozoic marine systems by the epeirogeny following the Appalachian orogeny. Severe contraction of the Basin occurred in the Triassic, as indicated by the distribution of the upper Spearfish-Lower Watrous and the Amaranth red-beds and evaporites. At that time, the basin was made up of two trapezoidal troughs: one trended northwest into Saskatchewan from an intersection in North Dakota with the other, which extended northeast from Wyoming to southwestern Manitoba (The Amaranth sub-basin). Structural blocks flanking this Triassic basin exercised shore-margin controls on sedimentation formats of the succeeding marine Jurassic basins.

Onshore flats dominated the Triassic depositional floor of continental to marine red-bed clastics and evaporites. These were succeeded by Middle Jurassic deeper water sedimentation, that progressed from sabkha-like bodies to off shore marine, as seen in the Upper Watrous, Gravelbourg, and Shaunavon Formations (Piper Group). Maximum expansion of the basin occurred during the Rierdon and Swift episodes of deposition; this was accompanied by uplifts of the Sweetgrass Arch, the Swift Current Platform and the Punnichy Arch along the northwestern and northern rims of the basin. Swift sedimentation was ended by progradation of continental sediments from central Saskatchewan and Manitoba in the north (Success Formation) and from Wyoming in the south (Morrison Formation).

The Jurassic and Jura-Cretaceous strata of southwestern Saskatchewan and the Triassic of southwestern Manitoba are major petroleum producing regions. The former comprises isolated shoreline sand bodies in the Shaunavon Formation and unconformity-bounded mesas, buttes and promontories in the Roseray and Success Formations. The Triassic reservoirs are permeable sand bodies in otherwise low-permeability sandy mudstones.

Christopher, J.E. (1984): The Lower Cretaceous Mannville Group, northern Williston Basin region, Canada; *in* The Mesozoic of Middle North America, edited by D.F. Stott and D.J. Glass; Canadian Society of Petroleum Geologists, Memoir 9, p109-126.

The Mannville Group of Saskatchewan is an unconformity-bounded clastic body comprising three main formations: Success, Cantuar and Pense.

The Success Formation, ranging in age from Kimmeridgian(?) to Neocomian, and distributed across the province as three large homologous bodies, is characterized by white, kaolinitic, sideritic and locally cherty, quartzose sandstones and mudstones up to 105 m thick. Its depositional slope was southward and southwestward from off the Precambrian Shield and its general depositional format is fluviatile-lacustrine, with some indications of early marine in the extreme south of the province. The Success is coeval with the Early Cretaceous Lakota Formation of the Williston basin, as well as the Jura-Cretaceous Morrison of the Fergus-Great Falls basin and, perhaps, the Swift sandstone of the Sweetgrass Arch.

In contrast, the Cantuar Formation is more varied in its lithological makeup and comprises three major facies:

a) Green biotite-chlorite rich tongues in the southwest (Atlas-Dimmock Creek Members) and in west-central Saskatchewan (Grand Rapids Formation). These yield eastward to the centrally distributed
b) Clearwater facies of marine, sequential or cyclic beds of black muds, bioturbated sands, mudstones and very argillaceous sandstones and well sorted sandstones; interrupted irregularly by fluviatile and deltaic marine channel sandstones, lagoonal mudstones and thin coals. The Clearwater facies grades eastward near Manitoba into
c) kaolinitic, quartzose sandstones feathering in from the Precambrian Shield. This facies also characterizes the underlying McMurray-Dina Member, which forms a regionally consistent unit of quartzose, locally kaolinitic sandstones, generally fluviatile to estuarine in depositional mode.

The Cantuar Formation overlies a high relief (100 m) unconformity and in general is a product of a marine invasion that extended from the Arctic to the Williston Basin. The seaway in Saskatchewan was relatively narrow and was thus more nearly estuarine. Provenances were the rising Cordillera (biotite-chlorite facies), older beds in the interfluves of the topography, as well as the Precambrian Shield.

The Pense Formation, wholly marine but retaining the cyclic depositional format of the Clearwater, overlies the Cantuar on an unconformity that locally cuts to the base of the latter on the Punnichy Arch. Four upward coarsening sequences of mudstone, bioturbated mudstone-sandstone and clean sandstones can be utilized as a yardstick for measuring the depth of each step in the subsidence of the seafloor.

Internal structural control of the Mannville basin was apparently exercised by basement blocks moving differentially along several major lineaments. These

linears also controlled the paths of formation fluids, including meteoric influx. The hydrodynamic potentiometric field appears to have exercised some control on the location of the major oilfield for Mannville oil districts of the province. Source beds are deduced to have been Paleozoic strata to the south and southwest.

Coombe, W. (1984): Gold in Saskatchewan; Saskatchewan Energy and Mines, Open File Report 84-1, 134p.

This report represents a summary of all gold occurrences, known to the writer, in the province of Saskatchewan. The report endeavours to condense, synthesize and interpret available data on gold and to describe and evaluate the mineral potential of known auriferous areas. As well, the report attempts to identify new areas for gold exploration.

The report is based upon non-confidential information available to the writer. The latter was derived principally from the Saskatchewan Mineral Deposits Index, company annual reports and other published data. In some instances, non-confidential assessment files of Saskatchewan Energy and Mines were consulted. The report was written at the request of Saskatchewan Energy and Mines and was completed during the period June to October, 1984.

Coombe, W., Lewry, J.F. and Macdonald, R. (1985): Regional geological setting of gold in the La Ronge Domain, Saskatchewan; *in* Gold in the Western Shield (Program and Abstracts); CIM Geology Division Gold Symposium and Field Tours, Saskatoon, Sept. 7-12, p20-21.

Over eighty gold occurrences have been found in the La Ronge Domain since the 1930s. Mineable reserves have more recently been outlined in at least two deposits.

The La Ronge Domain lies within the Lower Proterozoic 'Trans-Hudson Orogen' which extends approximately 5000 km from Greenland to the midwest U.S.A. The domain is part of a collage of Early Proterozoic volcano-plutonic arcs, batholiths, associated volcaniclastics and volcanogenic sediments lying between the Superior Craton to the southeast and the reworked Archean basement/Aphebian cover terrain to the northwest. The chemical composition of the magmatic rocks, together with radiometric and isotopic data suggest that the collage represents newly formed, and possibly accreted Proterozoic crust.

Plutons and migmatites of the Rottenstone Domain lie to the northwest. The junction with the Rottenstone Domain is partly defined by high strain zones including the Birch Rapids Straight Belt. To the southeast the junction with the adjoining Glennie and Kisseynew Domains is partly defined by the Stanley Shear Zone but elsewhere is gradational and structurally complex.

The La Ronge Domain has several lithostructural subdivisions. The Central Metavolcanic Belt is dominantly basaltic and intruded by gabbroic to granitic plutons. The volcanic geochemistry closely resembles that of a younger subduction-generated 'primitive' arc developed on oceanic crust. U-Pb zircon geochronology indicates that the arc volcanism and pre-to late-kinematic plutonism occurrred circa 1890 Ma to 1850 Ma ago. The plutons in the belt are mainly tonalitic to granodioritic, and are both homogenous and compositionally zoned.

The MacLean Lake Belt and Crew Lake Belt, to the southeast and northwest of the Central Metavolcanic Belt respectively, mainly comprise volcanogenic metagreywackes and mafic to felsic volcaniclastics. The MacLean Lake surpracrustals include intercalated polymictic metaconglomerates and are overlain by and infolded with arkosic molasse of the McLennan Group. Granitic plutons are rare in this belt but abundant in the Crew Lake Belt. The Nut Bay Belt to the southeast comprises foliated granitoids with subordinate and dominantly metavolcanic supracrustals. The Nemeiben Zone, forming the southwestern part of the domain, is lithologically similar but structurally more complex.

The Central Metavolcanic Belt has an attained grade of upper greenshist to amphibolite facies and is relatively undeformed, though local high strain zones occur. The MacLean Lake Belt has attained upper amphibolite to lower granulite facies grade locally and is much more deformed, incorporating flattened isocinal folds, fold-thrust stacking and other effects of extreme structural telescoping. Regional dips in the Central Metavolcanic and MacLean Lake Belts are to the west. The junction between the two belts is generally defined by the high strain McLennan Tectonic Zone, along which the Central Metavolcanic Belt structurally overlies the McLennan Group. Other subdivisions of the domain are complexly folded and locally disrupted by high strain zones.

Most gold occurrences in the La Ronge Domain have been found in the Star-Waddy Lakes area of the Central Metavolcanic Belt and in the Sulphide-MacKay Lakes area. The latter is a zone affected by prominent heterogenous high ductile strain across the junction of the Nut Bay and Central Metavolcanic belts. Vein and stratiform-type gold occurrences are present in both areas. Nearly 90 percent of the occurrences are vein-type, they are especially prevalent in the Star-Waddy Lakes area. In contrast stratiform occurrences are more conspicuous in the Sulphide Lake area.

About 60 per cent of the epigenetic vein-type occurrences are hosted by supracrustal rocks, primarily mafic flows/ pyroclastics but including felsic volcaniclastics. Other hosts include eipzonal granitic plutons (30%) and mafic intrusions (7.5%). Occurrences vary from simple lensoid/

podiform quartz-sulphide bodies to quartz-sulphide-(carbonate) stockworks. They commonly lie in structural traps, including dilation zones within ductile shears (PAP, 21 zone, Pie) and related brittle fractures (Discovery), fault zones (Jojay) and fractures related to pluton emplacement (Komis). Mineralization comprises pyrite with variable native gold, pyrrhotite, chalcopyrite, galena, sphalerite and tourmaline; arsenopyrite is present in the Sulphide Lake area. Trace molybdenite, stibnite, marcasite, hematite and magnetite occur locally.

Vein-type deposits form the most developed gold prospects; they are relatively low tonnage but locally high grade (i.e. 0.5 oz gold/ton) The mineralizing fluids may have been associated directly with synvolanic (or later) intrusion or have originated as metamorphic pore fluids, derived during amphibolite facies metamorphism. Ductile shear zones, developed during main thermotectonism, and later brittle fracture zones provided suitable permeable conduits for these fluids. Mineralization occurred mainly in relatively low P-T regimes in upper greenschist/lower amphiboilite facies host rocks. Komis vein-type mineralization in the Waddy Lake vicinity may be a direct product of magmatic-hydrothermal processes associated with plutonism. Mineralization in the Star Lake area may relate to flushing of fluids along ductile shear zones coeval with displacement along the McLennan Tectonic Zone.

Stratiform occurences are hosted mainly in felsic volcanic-volcaniclastic sedimentary sequences which were possibly deposited in proximal volcanic environments (Sulphide Lake, Wedge Lake). Mineralization comprises pyrite-pyrrhotite-arsenopyrite with minor native gold, chalcopyrite, galena and sphalerite. Stratiform occurences generally exhibit lower grade mineralization (i.e. 0.15 - 0.25 oz gold/ton) than the vein-type occurrences. The mineralization shows many epigenetic features in detail, such as variably concordant/discordant quartz-sulphide and sulphide veinlets within the stratiform zones. Gold may initially have been deposited within iron-rich exhalites and sediments during fumarolic activity associated with felsic volcanism. Epigenetic features may derive from local tectonometamorphic remobilization and/or introduction of later magmatic-hydrothermal fluids in the same zone.

The distinction between epigenetic and stratiform occurrences is complicated by the problems of distinguishing ductile shear fabrics from primary layering. For example many of the fine-grained laminated rocks in the Sulphide - MacKay Lakes originally mapped as supracrustal may be re-interpreted as the product of ductile shearing of plutonic or volcanic protoliths.

From our literature review, the La Ronge Domain contains one of the few documented Proterozoic gold belts. Similarities exist with gold occurrences in Archean terrains as well as in younger volcanic arc settings.

Dunn, C.E. (1984): An overview of geochemical studies in the Athabasca Test Area, Saskatchewan (abstract); *in* Program and Abstracts, 86th Annual General Meeting, Canadian Institute of Mining and Metallurgy, Ottawa, Apr. 15-19, p45.

Geochemical studies in the test area have produced some surprising and potentially significant results. The techniques can be divided into: (1) Regional studies — lake waters and sediments, peats and vegetation; (2) Detailed studies near uranium mineralization — lakes, soils, basal tills, peat, vegetation, and rocks.

Coordination of specialist studies has permitted comparison of techniques, and the wealth of data produced has added perspective to exploration strategy. Not all techniques are successful at detecting buried uranium mineralization, but an integrated study has helped to demonstrate and explain their relative effectiveness and practicality. Vital base-line information has been established that will be a constant source of reference.

Dunn, C.E. (1984): Biogeochemical prospecting for uranium and gold in the forests of Canada's Precambrian Shield (abstract); *in* International Seminar on Geobotany and Biogeochemistry in Exploration for Ground Water and Mineral Resources (Abstracts); Sri Venkateswara Univ., Tirupati, India, Nov. 27-30, p27-30.

Currently, biogeochemical prospecting for minerals in the vast expanses of forest in Canada is enjoying a resurgence of interest. This is because of the ever-increasing need to detect subtle indications of deposits, and the greatly improved analytical instrumentation which permits precise detection of low levels of elements in vegetation. Research studies are oriented toward a) establishing background levels of elements in various organs of common trees and shrubs; b) recognition of biogeochemical 'provinces' of metal enrichment in the vegetation; and c) determining to what extent the chemistry is altered in the vegetation growing in areas of known mineralization. An underlying theme to the studies is the development of rapid, practical, and cost-effective methods of exploration.

Dunn, C.E. (1984): Biogeochemistry as an aid to the exploration for precious metals in Saskatchewan, Canada (abstract); unpubl. paper presented at "Exploration for Ore Deposits of the North American Cordillera" symposium, Association of Exploration Geochemists, Reno, Mar. 25-28.

Twigs of shrub alder *(Alnus rugosa)* tend to absorb gold in higher concentrations than other common species in the northern forests of Saskatchewan. This plant is not cyanogenic, hence samples can be ashed to preconcentrate gold without loss of the metal as the volatile gold cyanide.

Samples collected in the vicinities of several mineralized zones commonly contain in excess of 50 ppb Au in the ash of the latest 50 cm of twig growth. Background values are about 10 ppb Au. A reconnaissance scale survey involving the collection of samples at 2 km intervals has outlined an area coincident with a major lithostructural domain within which ashed alder twigs contain from 20 to 130 ppb Au ($\bar{x}$ = 45 ppb Au). In sharp contrast, alders in a neighbouring area contain less than 10 ppb Au. It appears that this rapid regional approach to biogeochemical sampling in glaciated terrains may provide useful information on the gold potential of the underlying bedrock.

Platinum and palladium show a tendency to concentrate in twigs and trunk of black spruce *(Picea mariana)*; trunk of jack pine *(Pinus banksiana)*; and stems of labrador tea *(Ledum groenlandicum)*. Close to a worked out nickel-copper deposit that contained 3000 ppb Pt and 6000 ppb Pd, ashed spruce twigs yield up to 880 ppb Pt and 1350 ppb Pd. For both elements background levels in the vegetation are below 10 ppb.

Dunn, C.E. (1985): Biogeochemical prospecting for uranium and gold in Canada's forests (abstract); *in* The Hydrologic Cycle in Mineral Exploration and Geological Factors in Resource Development, Program with Abstracts; Geological Association of Canada, Newfoundland Section, Annual Spring Meeting, March 28, 29.

Dunn, C.E. (1985): Gold exploration in northern Saskatchewan by biogeochemical methods; *in* Gold in the Western Shield (Program and Abstracts), CIM Geology Division Gold Symposium and Field Tours, Saskatoon, Sep. 7-12, p39-40.

Exploration for gold in the Precambrian Shield of Canada is hampered by the extensive forest cover. Fortunately, most plants have the capacity of accumulating gold from the rocks, soils, tills, and groundwaters to which their roots gain access. Root systems are exceedingly powerful and corrosive (locally producing microenvironments less than pH 1), and an individual plant may have many tens of kilometres in total extent of roots and rootlets. These roots have literally millions of apertures through which nutrients may enter the living system. As a result, a mature plant is a highly sophisticated geochemical sampling tool which is capable of integrating the geochemical signature of several cubic metres of the substrate.

Gold accumulations vary substantially among plant species, within individuals, and between seasons. Interacting environmental and physicochemical forces control metal concentrations in plant tissues, and render their understanding difficult. However, systematic research into these controlling factors progressively adds to our understanding, such that biogeochemical prospecting is becoming an increasingly viable option to the small prospector and large mining company alike.

Twigs and leaves of shrub alder (*Alnus crispa*) generally accumulate gold in higher concentrations than other common species in the boreal forests. Background concentrations in ashed material are 10 to 20 ppb Au, with local enrichments up to 700 ppb Au. Highest concentrations occur in April in the twigs, prior to leaf growth. By June some gold has been flushed out of the twigs to the leaves, but with the higher concentrations occurring in the twigs. By August the picture has reversed, with leaves containing slightly greater amounts of gold than the twigs, and the over-all gold content of the shrubs has decreased. This phenomenon is attributed to the spalling from the leaves of waxes, salts and cuticles containing gold that has been flushed to the plant extremities. The importance of this observation is that a biogeochemical survey for gold, using live vegetation, must obviously be conducted in as short a time frame as possible for meaningful comparison of data. Greatest anomaly enhancement is obtained from twig collection in early spring.

Problems of seasonal vegetation can be circumvented by sampling dead vegetation — especially the outer scales of conifers. Scales of jack pine with up to 960 ppb Au, and black spruce with 450 ppb Au have been found in the La Ronge Domain. Background levels are commonly less than 10 ppb Au.

A survey has been conducted of various biogeochemical sample media from approximately 1,200 locations within a 300 sq km area of the La Ronge Domain. Results indicate a zone of enhanced levels of gold on either side of the Stanley Mission road (Lat. 55° 20'). Areas of known gold mineralization elsewhere show a positive response of gold enrichment in the vegetation. Furthermore, in several areas with no known mineralization gold concentrations

in vegetation are substantially elevated warranting closer investigation.

Several gold "pathfinder" elements exhibit local enrichment in certain parts of plants. For example, spruce bark locally contains elevated levels of arsenic, antimony and barium, whereas alder does not show a propensity to accumulate these metals. Conversely, molybdenum is rarely present in the spruce bark in excess of 2 ppm Mo, yet the latest one year of alder twig growth may contain over 100 ppm Mo. Each organ of each species has a different suite of element tolerances, hence accumulations.

Spatially, gold, arsenic and antimony are associated in spruce bark from trees growing near mineralization with these elements. However, there is commonly a negative barium anomaly over such mineralization, with a positive barium response displaced some tens to hundreds of metres away.

Other trace metals exhibit their own peculiarities with respect to concentrations in vegetation and association with zones of mineralization. Preliminary data indicate that bromine and sodium enrichment in some species may provide evidence of mineralization.

The type of mineralization with its concomitant development of physicochemical conditions in bedrock, soils, and waters, may play an important role in the development of a biogeochemical response. For example, gold associated with pyrite may be more readily dispersed into groundwaters than native gold, because of the acidic milieu generated by the sulphides. Consequently, the former case would give a broader (and probably more intense) biogeochemical response than the latter.

Thus many factors need to be taken into account when both establishing a biogeochemical sampling program, and interpreting the analytical results. At present base-line data are scanty, but realization of the controlling factors of trace metal uptake and dispersion is beginning to establish the biogeochemical method as an important tool in the search for subtle indications of concealed mineralization.

Dunn, C.E. and Sibbald, T.I.I. (1985): Biogeochemical prospecting for uranium and gold in the Precambrian Shield of Saskatchewan (abstract); paper presented at Prospectors and Developers Convention, Toronto, March 10-13.

Currently, biogeochemical prospecting for minerals in Shield terrain and in the Shield of Saskatchewan in particular is enjoying a considerable interest. This is because of the ever-increasing need to detect more subtle indications of deposits and the precise detection permitted by greatly improved analytical instrumentation. Research studies are oriented toward a) establishing background levels of elements in various organs of common trees and shrubs; b) recognition of biogeochemical 'provinces' of metal enrichment in the vegetation; and c) determining to what extent the chemistry is altered in the vegetation growing in areas of known mineralization. An underlying theme to the studies is the development of a rapid, practical and cost-effective method of exploration.

In northern Saskatchewan there is an abundance of uranium in the Athabasca Basin, particularly in proximity to the unconformity between metamorphosed crystalline rocks of the Hudsonian orogen and unmetamorphosed sandstones and conglomerates of the Precambrian (Helikian) Athabasca Group. Studies of uranium uptake by species common to that area have shown that black spruce (*Picea mariana*) is particularly sensitive to the presence of uranium. Twigs of black spruce are able to accumulate unusually high concentrations of uranium without noticeable effects on plant growth. Locally, concentrations are over 2000 ppm U in twig ash, whereas background levels are 2 to 3 ppm U. By systematically sampling the latest 10 years of spruce twig growth, it has become possible to produce a biogeochemical map of many thousands of square kilometres of the Athabasca Basin. One area surrounding Wollaston Lake, on the east side of the Basin where many major orebodies are located, has emerged as an immense uranium biogeochemical anomaly. Over 1000 spruce trees sampled in an area of 10,000 km^2 all contained in excess of 10 ppm U in twig ash. In this 10,000 km^2 area there is a core of 3,000 km^2 within which the twigs contain in excess of 50 ppm U, and an inner core of 1000 km^2 where all trees sampled have over 100 ppm U in ashed twigs. After examining the possible causes of this unusually large and pronounced anomaly, it is concluded that formation waters containing traces of U derived from the many rich orebodies are the most likely source.

Other high regional uranium concentrations in spruce twig ash surround the Beaverlodge and Cluff Lake uranium camps. Natural levels of concentration range to 290 ppm U in the Beaverlodge area and to 246 ppm U in the Cluff Lake area.

On a detailed scale a biogeochemical response to U orebodies which lie beneath 150 m of Athabasca Group clastics has been recorded. Also, intense anomalies occur in several areas, as yet undrilled. Upward migration of U ions, preferentially along subvertical fractures, is one process invoked to explain anomalies.

Gold-distribution studies of plants in the northern forests show that alder *Alnus sp.* tends to concentrate gold to a greater degree than other common genera. A preliminary regional survey of the gold content of alder twigs in the southern part of the La Ronge Gold Belt of central Saskatchewan has revealed an area where concentrations are relatively high. There is a 60 km long zone in which

the mean gold content of ashed alder twigs was 45 ppb (n 27), compared to another 60 km long zone within which a similar number of samples averaged only 8 ppb Au (n 17). Compilation of data from over 1000 new sites sampled in the former zone, during the summer of 1984, shows that concentrations are locally up to 200 ppb Au in ashed alder twigs. There is a good response to known near-surface gold mineralization, and vegetation samples with anomalous gold concentrations also occur at a few localities where outcrop is absent and there is no known mineralization. Thus, it appears that this biogeochemical method may provide an indication of the near-surface gold potential of an area. However, as a note of caution, it has been found that seasonal variations in chemistry occur within alder twigs between the months of June and August. A threefold reduction of gold content may occur. Samples collected over an extended time frame may thus not be directly comparable.

Recent work has shown that the outer bark of conifers may also be an effective sample medium for gold. Unlike alder twigs, bark does not exhibit seasonal variation; however, there does appear to be chemical heterogeneity within the bark profile according to coarseness of bark scales and degree of fungal development. A spruce bark survey over part of the historic Goldfields gold camp of northern Saskatchewan has yielded some encouraging results. Over the Box Mine orebody, which is well exposed at surface, values of up to 200 ppb Au were obtained and in areas adjacent up to 625 ppb Au in ashed bark. By contrast, the gold response over the equally well exposed and geologically similar Athona Mine orebody was not significant.

Careful research is required to unravel the complex processes which control metal uptake by plants, such that the exploration geologist is provided with a tool with known performance characteristics. The haphazard application of the biogeochemical method, which has characterized many surveys, has often led to disillusionment. Clearly there are pitfalls and equally clearly more research is required to define limitations of different biogeochemical techniques.

Dunn. C.E., Ek, J. and Byman, J. (1985): Uranium biogeochemistry: a bibliography and report on the state of the art; International Atomic Energy Agency, Technical Document 327.

Fuzesy, A. (1984): Index to assessment work in the Athabasca Mining District of Saskatchewan; Saskatchewan Energy and Mines, Miscellaneous Report 84-8, 33p (supplement to Miscellaneous Report 79-5).

Fuzesy, A. (1985): Assessment work catalogue, La Ronge Mining District; Saskatchewan Energy and Mines, Miscellaneous Report 85-5, 126p.

Geological Survey of Canada (1985): Regional lake sediment and water geochemical reconnaissance survey (NTS 64E and parts of 74A and H); Geol. Surv. Can., Open File 1106, 92p (incl. 20 maps).

Geological Survey of Canada (1985): Regional lake sediment geochemical reconnaissance data (NTS 63M, 64D and parts of 63K, L, N, 73I, O, P and 74A); Geol. Surv. Can., Open File 1129, 150p (incl. 8 maps).

Gilboy, C.F. (1985): Basement geology, part of the Cree Lake (South) area; Saskatchewan Energy and Mines, Report 203, 47p.

The sub-Athabasca Group crystalline basement of the Cree Lake area is composed mainly of felsic gneisses, some of probable Archean age. Supracrustal rocks, commonly pelitic or semipelitic in composition, crop out sporadically throughout the region as lenses or as narrow bands, up to about 1 km wide and 60 km long. Some, and perhaps all, are of probable Aphebian age.

The rocks in the extreme east probably lie within the Wollaston Domain, those in the centre, in the Mudjatik Domain, and those in the west, in the Virgin River Domain. Whereas the junction between the Wollaston and Mudjatik Domains is gradational, the Mudjatik and Virgin River Domains are separated by a major tectonic lineament, the Cable Bay Shear Zone.

In the Wollaston Domain, compositionally and texturally homogeneous granitic gneisses are overlain by tourmaline-bearing metasediments of the Wollaston Group which show few signs of migmatization. No major folds have been recognized, but foliation trends vary from northeasterly in the southern part of the map area to northwesterly in the northern part.

In the Mudjatik Domain, the felsic gneisses show more compositional and textural variation. They have been folded, along with highly migmatized metasediments, into dome-and-basin structures. Hypersthene, indicative of granulite facies metamorphism, is widespread throughout most of the domain.

In the Virgin River Domain, felsic rocks are commonly homogeneous. They differ from their counterparts in the Wollaston Domain in that they tend to lose

thermotectonically superimposed fabrics through recrystallization or remobilization. The metasediments show few signs of migmatization or the development of tourmaline. They also lack cordierite, which is so abundant in the Mudjatik and Wollaston Domains. Foliation and lithologic trends indicate a structural style similar to that of the Wollaston Domain. Widespread late-stage retrogression has affected both the felsic gneisses and the supracrustal rocks in the western part of the map area.

Four deformational events (D_1 to D_4), all of probable Hudsonian age, have been recognized. The first three phases are associated with a prolonged period of upper amphibolite to granulite facies metamorphism, which peaked at about 4.5 kb and 725°C, and destroyed most of the primary structures in the supracrustals. The first deformation (D_1) produced a regionally developed gneissic foliation and/or schistosity; no genetically related folds have been identified. During the second phase (D_2), best seen in the Mudjatik Domain, large west-northwest-trending upright folds developed. The production of later upright folds with northeast-trending subhorizontal axes resulted in the formation of domes and basins during the third phase (D_3). By this stage, metamorphic conditions in the Mudjatik Domain had waned to a pressure of about 3.7 kb and a temperature of about 650°C. The final event (D_4) was characterized by shearing which, although generally localized, attained considerable geological importance in the Cable Bay Shear Zone. It was accompanied by regional retrogression, particularly in the west.

Intrusive rocks, mostly granitoids, form recognizable plutons in the western part of the Mudjatik Domain. Most seem to have been emplaced before or during D_1. However, late, mostly massive granites were emplaced in both the Mudjatik and Virgin River Domains as plugs and plutons and, more commonly, as sharply cross cutting dykes. Uplift and erosion was followed by deposition of the Athabasca Group conglomerates and sandstones under mainly fluviatile conditions.

The injection of diabase dykes, mainly concentrated in a 6 km wide northwest-trending zone (the Cree Lake dyke swarm), at about 1100 to 1200 Ma was followed by regional fracturing and some faulting.

Although no economically viable mineralization is presently known, the geologic setting is suitable for the formation of Key Lake-type uranium deposits. Of marginal interest is the VH iron deposit, which is located close to the western edge of the area and contains an estimated 23 to 27 million tonnes of ore grading 32 percent Fe.

Gilboy, C.F. (1985): Compilation bedrock geology, Cree Lake, NTS area 74G; Saskatchewan Energy and Mines, Report 237 (1:250,000 scale map with marginal notes).

Gracie, A.J. and Gray, L.J. (1984): Index to La Ronge core collection; Saskatchewan Energy and Mines, Open File Report 85-3, 145p.

The Saskatchewan Energy and Mines core collection comprises mineralized and geologically important diamond-drill cores from northern Saskatchewan. It is housed primarily in La Ronge, in a warehouse (measuring 23 by 22 m) attached to the Precambrian Geological Laboratory. Steel core racks provide storage for some 50,000 m of complete and concentrated cores, filling about 50 percent of warehouse capacity. A core examination room (9 by 5.5 m) attached to the administrative office of the laboratory has a core splitter, rock saws, microscopes and all equipment required for detailed logging of core. A small interim storage facility is also maintained in Denare Beach by the Resident Geologist's office in Creighton.

A core collection program was started by the department as early as 1965; however, the decision to concentrate on mineralized and geologically important cores was not made until 1977. Since that time, with the cooperation of the mining industry, an excellent nonconfidential selection of cores from uranium deposits in northern Saskatchewan has been assembled. Base metal and gold properties are also represented in the collection, although not as strongly as uranium. Nonconfidential diamond-drillhole location maps, logs, assays and other relevant data support and illustrate all cores stored in the laboratory. Whenever possible, core from individual holes, or cross-sections of holes, across deposits which have been described in the literature have been acquired.

In addition to the core collection, there are suites of hand samples from a large number of mineral properties in northern Saskatchewan, and specialized core exhibits illustrating:

1) stratigraphy of the Athabasca Group, and
2) basement rock types characteristic of different lithostructural domains.

The present inventory is of all cores stored in the La Ronge warehouse as of April 1, 1984. It identifies the geographic location of individual cores by drillhole latitude and longitude and on 1:250 000 scale maps. It also gives full particulars of each hold (company, mineral disposition, exploration commodity, date, hole number, core size, hole bearing and inclination, meterage (footage) of sample core, reference to other available exploration data and storage location).

Grauch, R.I., Leventhal, J.S. and Harper, C.T. (1984): Organic material from the Cluff Lake (Canada) uranium district: its nature and paragenetic implications of the included mineral assemblages (abstract); 27th International Geological Congress, v9, pt1.

Organic material from Precambrian, unconformity, uranium orebodies, Claude and D, in the Cluff Lake deposit, Canada, was emplaced after a major uranium mineralizing event and prior to the formation of clay-rich veins. Emplacement may have taken place in fracture controlled voids, but preexisting uraninite was also replaced.

The organic material has highly variable reflectance and anisotropism. Light-gray anisotropic organic material occurs as halos immediately adjacent to uraniferous phases. At the D orebody an isotropic, inclusion-free, sulfur-rich form of organic material transects the earlier organic material. The sulfur content of matrix organic material from the Claude orebody have an unusually light $\delta^{13}C$ of -44 permil; entrapped methane has a $\delta^{13}C$ of -48 permil. Pyrolysis of the organic material yield predominantly one- and two-ring substituted aromatics.

Inhomogeneously distributed mineral inclusions in the organic material are generally very fine grained (<50μm), anhedral, and embayed. The inclusion assemblage is uraninite, coffinite, galena, galena (with traces of selenium and arsenic), pyrite, gersdorffite, and altaite (PbTe). For the Claude orebody this assemblage indicates a more complex history than previously recognized or a remote source for the inclusions. Illite(?)-rich veins containing minor amounts of quartz, potassium feldspar, and pyrite; trace amounts of the inclusion assemblage; and corroded fragments of organic material cross-cut the Claude organic material.

The Cluff Lake organic material has many similarities to organic material from the Witwatersrand (South Africa) gold/uranium district, but, unlike most of the Witwatersrand material, was emplaced long after the main mineralizing event.

Gullov, P. (1984): Saskatchewan; *in* Industrial Minerals in Canada - A Review of Recent Developments; Industrial Minerals, no 200, p93-105.

Saskatchewan's industrial mineral sector is dominated by the potash industry which accounted for about 89% of the value of all industrial mineral sales in 1982 and about 65% of all metallic and industrial mineral sales in the same year excluding fuel minerals. In addition to potash, Saskatchewan is Canada's major natural sodium sulphate producer, accounting for about 92% of the value of national production. Other industrial mineral production in the province includes sand and gravel, salt, sodium bentonite, clay and clay products, and cement. Important deposits with significant potential for future development include carnallite, silica sand, limestone, volcanic ash, building stone, graphite, and ceramic clays. Materials for future consideration and investigation include phosphate, gypsum, manganese and leonardite.

Gullov, P. and Korpijaako, E. (1984): Potential of peat as a domestic fuel in northern Saskatchewan, Canada; *in* Proceedings of the 7th International Peat Congress, Dublin, Ireland, June 18-23, Vol. II, p227-236.

A multi-phase program was initiated by Saskatchewan to assess the fuel peat resources of the Province and their potential as an alternate fuel in the north. Much of the work was funded jointly by the Federal and Provincial Governments. Saskmont Engineering Limited, a Monenco Company, was contracted to carry out a part of the program work. A significant proportion of the peatlands of Saskatchewan south of the permafrost region contain fuel peat. A small deposit near the community of Buffalo Narrows in northwestern Saskatchewan was selected as a demonstration site. About 4 ha were prepared for the production of sod peat. In 1982 the feasibility of production was confirmed with the production of a small quantity of sod peat. A test program to fire locally produced sod peat supplemented by imported sods was implemented in a number of homes. For this purpose two Finnish, one German and two Canadian built domestic furnaces were used and closely monitored for performance data.

Harper, C.T., Thomas, D.J. and Watters, B.R. (1985): Geology and petrochemistry of the Star-Waddy Lakes area (abstract); *in* Gold in the Western Shield (Program and Abstracts); CIM Geology Division Gold Symposium and Field Tours, Saskatoon, Sept. 7-12, p21-23.

The Star-Waddy Lakes area lies along the eastern part of a northeasterly trending early to mid Proterozoic volcanosedimentary-plutonic belt referred to as the La Ronge domain. The belt is composed of an eastern zone of metavolcanics and metavolcaniclastics and a western zone of largely 'greywacke' metasedimentary units, all of which are intruded by basic to acid bodies. Along the southeastern margin of the La Ronge domain feldspathic meta-arenites and metaconglomerates of the McLennan group structurally underlie the volcanics.

In the Waddy Lake area, the supracrustal succession is

interpreted as comprising a basal sedimentary assemblage, followed by a volcanic pile with ultramafic flows (komatiitic) at the base, succeeded by several cycles of mafic to felsic flows, pyroclastics and minor intercalated sediments. At least locally, some basic to felsic and submarine to subaerial cycles culminate in the formation of felsic domes, particularly in the Upper Waddy Lake area. In contrast, the Star Lake area is characterized by a substantial thickness of basic to intermediate submarine to subaerial pyroclastic deposits which increasingly give way to more flows and less pyroclastics southwards. Felsic metavolcanics are notably less common at Star Lake compared to the Waddy Lake area. Intercalated metasedimentary units are generally rare in the Star Lake area although pyroclastics grade laterally into volcanogenic metasedimentary rocks to the west.

The volcanosedimentary succession is intruded by a variety of relatively uniform to complex multiphase ultrabasic and basic to acid bodies. Field relations suggest an 'early', possibly subvolcanic, episode marked by composite intrusions ranging from gabbro-diorite to granite as well as by the emplacement of many of the ultrabasic to basic intrusions. A 'later' plutonic event is distinguished by more homogeneous uniform acid intrusions.

Geochemical evidence suggests that the extrusives were emplaced in an island arc environment, an interpretation supported by geologic evidence. Metavolcanic rocks from both the Waddy and Star Lake areas display similar characteristics on variation diagrams (e.g. AFM and Jensen cation plots) in that the dominant trend is calc-alkaline with some basic to intermediate types having a mildly tholeiitic character. The calc-alkaline varieties are characteristically high in Al and the suite as a whole is low in Ti. A few samples from the southern end of South Waddy Lake display komatiitic to basaltic-komatiitic affinities.

The relatively immobile minor and trace elements (e.g. Ti, Zr, Nb, Y, Cr) provide reliable characterization of the metavolcanics, particularly of the basalts which have highly distinctive trace element properties. Geochemical patterns for the basalts (using concentrations normalized to mid-ocean ridge basalt) are similar to those for modern volcanic arc basalts, being enriched in incompatible elements of low ionic potential (e.g. Sr, K, Rb, Ba) and depleted in those of high ionic potential (e.g. Ti, Y, Yb, Sc, Hf, Zr). Rare earth element patterns show enrichment in the light rare earths (La/Lu ratios of 3-21 for andesites and 2-7 for basalts) with little or no Eu anomaly. Low initial $^{87}Sr/^{86}Sr$ ratios (0.7017 - 0.7019) are consistent with a subduction related origin for the volcanics.

A number of preliminary observations can be made regarding the chemistry of intrusive rocks in the Star Lake area. The Star Lake Pluton is zoned and shows a wide range in composition from gabbro-diorite in the marginal zone to diorite - monzonite - granodiorite in the intermediate zone and granite in the core. The origin of the zoned character is not yet known but compositionally there is a transition from margin to core and all rock types appear to be linked genetically. Chemically, rocks of the pluton are calc-alkaline and very little different from the calc-alkaline volcanics in the area.

Uranium-lead (zircon) ages from metavolcanics indicate volcanism occurred about 1880 Ma with major plutonism occurring around 1866 Ma. Initial volcanism (eg. komatiites, Lower Waddy Lake) may be considerably older since the ages were obtained from felsic meta-volcanics which may be situated relatively high in the volcanic pile.

The volcanosedimentary succession in the Star-Waddy Lakes area has undergone polyphase deformation. In the Waddy Lake area, large scale folding is manifested in a wide variety of arcuate and triangular patterns with variable orientation of axial planes and fold axes. Major fold closures are not recognized in the Star Lake metavolcanic sequence although tight to isoclinal folds with northeast-trending axial surfaces are common in metasedimentary units west of the metavolcanics. Inhomogeneous strain characterizes much of the Star-Waddy Lakes area in the form of zones of extreme extensional fabrics, discrete shearing, as well as broader zones of cataclasis and structural slicing. Strain gradients are typically very steep throughout the area with zones of high strain juxtaposed with areas of relatively minimal deformation. Dilation structures tend to favour these zones of highly contrasting strain. Late, brittle fracturing, faulting and shearing are widespread and appear to be particularly important as a loci for gold mineralization in both areas. Metamorphic data from the Star-Waddy Lakes area indicate that upper greenschist to lower amphibolite facies conditions were attained.

The most persistent features of gold mineralization in the Star-Waddy Lakes area are: 1) structural control; 2) quartz veining with associated wall rock alteration particularly represented by silicification, pyritization, and chloritization; 3) close association with intrusive rocks; 4) a preference for mafic to intermediate volcanic and intermediate to felsic intrusive host rocks; and 5) elevated base metal contents in bedded or massive sulphides and an association with arsenopyrite-bearing mixed facies iron-formation. The genesis of the gold occurrences in the Star-Waddy Lakes area is similar to that of other greenstone belts with both syngenetic and epigenetic/ metamorphogenic processes playing important roles.

Johnston, W.G.Q. (1984): Geology of the Wathaman Lake (East) area; Saskatchewan Energy and Mines, Open File Report 85-1, 65p.

The Wathaman Lake (east) area (NTS 64D-13E), covering approximately 427 km^2, lies between Latitudes 56^{0}45' and 57^{0}00'N and Longitudes 103^{0}30' and 103^{0}45'W. The area is centred approximately 217 km northeast of La Ronge and 145 km west of Lynn Lake, Manitoba. Highway 105, a gravel tote road to Rabbit Lake, extends through the central part of the map area. The report and accompanying maps are based on 140 geologist-days fieldwork in 1973. Outcrop is relatively abundant throughout most of the area, nearly 28 percent of which is lakes.

Except for some biotite migmatites with lenses of biotitic gneisses in the southeast, the area is largely underlain by four distinctly different granitic rocks of at least three separate ages. Whole rock analyses suggest that, with decreasing age, the granitic rocks are richer in potassium fields par. A younger granitic rock in the northwestern part of the area is compositionally zoned. The two younger granitic rocks contain magnetite and have high magnetic relief, in contrast to low featureless magnetic relief of the two older granodiorites. The second oldest granitic rock, a granodiorite, is the most extensive map unit, underlying more than one-third of the area; in some localities, it contains abundant inclusions of supracrustal rocks. Contacts of these inclusions with the granodiorite are sharp and their character and original features were preserved.

The youngest Precambrian rock, relatively fresh tholeiitic diabase, occurs largely as dykes which vary in strike from north to nearly 330^0 and dip eastward at relatively low angles in some localities. These dykes appear to be extensively faulted by northeast-trending faults, some of which may belong to the same fault set as those along the prominent topographic lineaments which extend beyond the area through Buss Lakes to the southwest. Two diabase dykes are extensively jointed and slickensided, indicating extensive post-dyke movement along the fractures they occupy. Due to its extensively fractured nature, the diabase was more readily eroded and outcrops are relatively sparse.

Maps showing the bedrock and Quaternary geology at a scale of 1:63, 360 accompany the report, as well as maps at the same scale showing geochemical data for Ni, Cu, Zn and Pb in over 700 bedrock and soil samples.

Lane, D.M. (1985): Souris River Formation in Southern Saskatchewan; Saskatchwan Energy and Mines, Report 92, 72p (reprint of a report originally published in 1964).

Lee, N. (1984): Index to POD File; Saskatchewan Energy and Mines, Data File 5.

Lewry, J.F. and Slimmon, W.L. (1985): Compilation bedrock geology, Lac La Ronge, NTS area 73P/73I; Saskatchewan Energy and Mines, Report 225 (1:250,000 scale map with marginal notes).

Lewry, J.F., Sibbald, T.I.I. and Schledwitz, D.C.P. (1985): Variation in character of Archean rocks in the western Churchill Province and its significance; *in* Evolution of Archean Supracrustal Sequences, ed. L.D. Ayres, P.C. Thurston, K.D. Card and W. Weber; Geol. Assoc. Can., Spec. Pap. 29, p239-261.

Trans-Hudson Orogen in Western Churchill Province includes the Churchill-Superior Boundary Zone, the main Hudsonian Mobile Zone, which is divided into Southeastern Complex, Hottenstone-La Ronge Magmatic Belt and Ensialic Mobile Zone, and the cratonic Amer Lake Zone. Archean basement extends throughout the Ensialic Mobile and Amer Lake Zones but occurs only locally to the southeast. Basement in the Ensialic Mobile Zone suffered ductile remobilization during high grade Early Proterozoic thermotectonism, and the Archean record is obscured. The Amer Lake Zone, affected mainly by low grade, brittle to plastic zonal reworking, shows widespread preservation of Archean features.

Crustal blocks in the Amer Lake Zone represent different Archean crustal levels, varying in character and preservation of Archean supracrustal units. The western Taltson and Queen Maud Blocks comprise deep crustal granulites with minor Archean supracrustal units. Eastern blocks show greenschist to granulite facies metamorphism, probably of several ages, and generally represent higher Archean crustal levels. Greenstone belt assemblages occur in the southeastern Ennadai and Tulemalu Blocks and in parts of Committee Bay Block. More stable platformal assemblages typify Armit Lake Block and most of Committee Bay Block. Archean events at least as old as 3 Ga are discernable. Present relations between the blocks, and across Slave-Churchill boundary, were largely established prior to, and maintained throughout, the Early Proterozoic.

Available data indicate Early Proterozoic subduction and collisional orogeny in Western Churchill Province. Differences in basement reworking are related to variations in thermal regime and compressional events in overriding Slave-Churchill continental lithosphere, and to reworking of possible southeastern microcontinental remnants during collision. Present or former continuity of Archean continental crust between Slave-Churchill and Superior Provinces is unproven.

Macdonald, R. and Slimmon, W.L. (1985): Bedrock geology of the Greater Beaverlodge area, NTS 74N-6 to -11; Saskatchewan Energy and Mines, Map 241A, scale 1:100,000.

Parslow, G.R. and Gaskarth, J.W. (1984): Geochemistry of the East Amisk area; Saskatchewan Energy and Mines, Open File Report 84-23, 156p.

Over the period 1978-83 Saskatchewan Energy and Mines funded the "Flin Flon Base Metals" project; this project initially concerned the compilation of all non-confidential assessment files in the area and latterly involved the collection and chemical analysis of representative rock samples in the area.

This report concerns the data resulting from a field survey and sample collection project carried out in 1979. The objectives of the project were:

a) Geological documentation of economic and related mineral occurrences and classification of same.
b) Evaluation of the geological controls and origin of mineralization in individual and groups of occurrences, through field and laboratory studies.
c) Determination of criteria for forecasting mineral exploration potential.
d) Appraisal of the effectiveness of mineral exploration techniques.

Data concerning (a), the compilation of assessment files from NTS areas 63K and 63L, was completed in 1979 and became available as Open File 82-6 in 1982; this report concerns the remaining three objectives for the east Amisk area. Similar studies for the Annabel Lake, Hamell Lake and Hanson Lake areas will be reported upon in due time.

Pearson, J.G., McDougall, F.H. and Galley, A.G. (1985): The geology and evolution of gold deposits in the Flin Flon - Amisk Lake area; *in* Gold in the Western Shield (Program and Abstracts); CIM Geology Division Gold Symposium and Field Tours, Saskatoon, Sept. 7-12, p32-33.

The gold occurrences concentrated in the Flin Flon and Amisk Lake areas of Saskatchewan are in different geological environments which illustrate their different metallogenetic evolution.

In the Flin Flon area gold occurrencess lie in both felsic and mafic volcanic rocks of the Amisk Group as well as intermediate to felsic P_2 (Boot Lake Complex, Reynard Lake) and P_3 (Phantom Lake Granite) plutons. Within the volcanic rocks quartz-sulphide veins, such as the Newcor, Cor, Unity and Bomber Lake occurrences, occupy narrow conformable to semi-conformable fractures. These zones are associated with narrow zones of alteration and deformation and appear to be older than the P_2 and P_3 intrusive bodies. Cross-cutting relationships indicate that the other volcanic-hosted deposits (the Rio and MacMillan Mines and the Dee occurrence) post-date intrusion of the Phantom Lake Granite. As well, these deposits are associated with zones of intense carbonate alteration and some quartz veining. At the Rio Deposit gold mineralization is associated with massive and disseminated pyrite in a carbonate alteration envelope while the Dee and MacMillan deposits are quartz veins with a carbonate-rich envelope.

Gold mineralization and alteration in the pluton-hosted deposits is fracture controlled. Phylitic and argillic alteration types are present in the Phantom Lake Granite whereas in the Boot Lake Complex a zonation from potassic quartz-feldspar-chalcopyrite outward through quartz-chloride to epidote-hematite is present. The mineralized zones occur as disseminated and massive pyrite-chalcopyrite (Yellow Jacket, I M C) and a vuggy gold-quartz-pyrite-molybdenite-tungsten veins (Phantom Lake Mine).

In the north Amisk Lake area the gold deposits are within supracrustal rocks or subvolcanic intrusives, none are within P_2 granitoid plutons. The deposits in the Missi Island area are associated with subvolcanic rhyolite and dacite intrusives and their extrusive equivalents with both structural and stratigraphic controls (Gull Island, Beaver, Laurel Lake). Widespread alteration associated with the deposits include carbonatization, silicification and sericitization. These deposits also have distinct major element (SiO_2, K_2O, Na_2O) and trace element (Cu, Zn, Au, Hg, As, Sb) alteration haloes and consist of pyrite, chalcopyrite, sphalerite and/or tetrahedrite.

Also in the north Amisk Lake area are a number of significant gold-quartz vein systems associated with Amisk and Missi sedimentary rocks (Monarch and Graham Mines, Robinson Creek) and/or major fault zones (Duplex, Kent, Amisk Syndicate). These deposits have similar (although narrower) alteration haloes and have undergone deformation processes similar to that recognized in deposits on Missi Island indicating that the gold-quartz veins were emplaced during or shortly after volcanism.

The differences in age, host rock lithology, alteration and style of mineralization indicate a fundamental difference in the fomation of gold deposits in the Flin Flon and Amisk Lake areas. In the Amisk Lake area in the intense alterations along fractures and other zones of porosity, the widespread geochemical alteration haloes, and the

setting of the deposits within the supracrustal rocks is indicative of precious metal, hydrothermal system in a near surface environment. In the Flin Flon area most deposits post-date the P_2 and P_3 plutons and are accompanied by distinctive alteration zones. This indicates that the mineralizing fluids were generated late in the geologic evolution of the area, possibly in a porphyry system.

Scott, B.P. (1985): Geology of the Upper Clearwater River area; Saskatchewan Energy and Mines, Open File Report 85-2, 26p.

The most common rock is felsic granulite, of probable Archean age. It occurs with megacrystic granite and the Careen Lake Group of mixed metasediments which were deformed about east-northeast-trending fold axes and metamorphosed at lower granulite grade.

In the southeast corner of the area, felsic granulite and mafelsic gneisses were intruded by anorthosite, which in turn was intruded by medium-grained granite. Retrograde metamorphism to amphibolite facies accompanied folding about north-northeast-trending axes and was followed by cataclasis along north-northeast trending surfaces. Several zones in the southeast corner of the area were mylonitized.

Major faults trend north-northwest and north-northeast. Late dykes ranging from granodioritic to doleritic are parallel to these faults and may be related to the Cree Lake diabase dyke swarm.

Sibbald, T.I.I. (1984): Overview of the geology of the test-area (abstract); *in* Program and Abstracts, 86th Annual General Meeting, Canadian Institute of Mining and Metallurgy, Ottawa, April 15-19, p45.

The test area straddles the eastern Helikian Athabasca Basin edge and encompasses several sub-Athabasca unconformity type uranium deposits. These occur below Athabasca Group clastics up to 300 m thick in the west of the area. The basement falls within two lithostructural domains, the Wollaston domain in the east characterized by Aphebian shelf-facies supracrustals and the Mudjatik domain in the west largely subcropping below the Athabasca cover and comprising Archean granite and Aphebian supracrustal elements. The geology of the area and its contained uranium deposits is reviewed and the impact of the NEA/IAEA program examined.

Sibbald, T.I.I. (1985): Geology and genesis of the Athabasca uranium deposits (abstract); paper presented at International Atomic Energy Agency meeting "Recognition of Uranium Provinces", London, September 25-27.

The Athabasca Basin contains some 14 percent of the reasonably assured, low cost uranium reserves of the free world. It comprises a 1400 m thick redbed succession, the Athabasca Group of Paleohelikian (ca. 1450 Ma) age and occupies an area of some 100,000 km^2. Fluviatile quartz sandstones and conglomerates give way upward to finer marine clastics and these in turn to stromatolitic and oolitic dolomite. Cross-cutting northwesterly trending diabase dykes are dated at between 938 and 1230 Ma.

The Athabasca Group is underlain by a lateritic weathering profile in crystalline basement rocks belonging to two major subdivisions of the Saskatchewan Shield, the Cree Lake (Mobile) Zone and the Western Craton. These are separated by a major shear zone, within a zone of low gravity, which is locally intruded by Hudsonian (ca. 1750 Ma) uranium enriched 'granite'. The Cree Lake high-grade metamorphic zone comprises Lower Proterozoic shelf-type supracrustals (Wollaston Group) overlying predominantly granitoid basement, which was variably remobilized into gneiss domes and recumbent gneiss lobes during Hudsonian (sensu lato) orogenesis. In part, the supracrustals have become incorporated in the granitoid infrastructure. The Western Craton shows similar ages of rocks, but on a large scale has suffered plastic rather than ductile deformation, with the development of geologically complex zones of Hudsonian (sensu lato) reworking surrounding Archean granulite facies cratonic nuclei.

Recognizable controls of Athabasca Basin uranium mineralization are: a) the sub-Athabasca Group unconformity, b) fracturing and faulting, and c) graphite in basement rocks. The deposits exhibit, to varying degrees, complex mineralogy and geochemistry (U $\pm$ Ni, Co, As, Cu, Pb, Zn, Ag, Au, Pt-group elements, Mo, V, Se, Mn and Fe). They are surrounded by extensive argillic alteration haloes in the Athabasca Group and more restricted haloes in the basement. Redox relationships are characteristic of most deposits. Dating of pitchblende and alteration minerals suggests epigenetic emplacement beginning 1350 Ma ago. Fluid inclusion studies indicate deposition from saline mineralizing fluids at temperatures between 150°C and 225°C.

The most acceptable model of deposit genesis, the diagenetic-hydrothermal model, involves interaction of hot, oxidized, metalliferous formational waters of the Athabasca Group with the underlying 'reduced' basement. Mineralization was episodic and likely triggered by tectonic events, possibly related to diabase dyke emplacement and/or uplift. The model requires neither local repeated enrichment by diverse processes throughout earth history, nor the existence of a specialized uranium-enriched source.

Sibbald, T.I.I. and Jiricka, D.E. (1985): Geology of the gold deposits, Goldfields, Saskatchewan; *in* Gold in the Western Shield (Program and Abstracts); CIM Geology Division Gold Symposium and Field Tours, Saskatoon, Sept. 7-12, p33-35.

The Goldfields area, on the north shore of Lake Athabasca, was active in the thirties and early forties. In 1934, Tom Box discovered gold mineralization in quartz veins in pyritized 'granite' at the site of what was to become the Box Mine of the Consolidated Mining and Smelting Company of Canada Ltd. In the rush of activity that followed numerous other gold occurrences were found, the most significant of these being the Athona and Frontier prospects which underwent underground development but did not reach production.

Probable reserves identified to date in the Box and Athona deposits amount to some 3.5 million tons grading an average of 0.07 oz gold/ton. Some 10 to 15 million tons of lower grade, possible reserves are also reported at the Box. From 1939 to 1942, the mine produced, from underground, 64,066 ounces of gold from ore grading 0.0452 oz gold/ton at a cost of between $1.5 and $2.0 a ton.

The Goldfields area is underlain by supracrustal rocks intruded by mafic bodies and invaded by 'granite'. The supracrustals, thought to be of Lower Proterozoic age, are characterized by a shelf-type succession metamorphosed under lower - middle amphibolite facies conditions into quartzites, quartz-mica schists, dolomitic marbles, diopsidic calc-silicates and cordierite-anthophyllite-biotite schists. Amphibolites of presumed igneous origin form concordant to subcordant units up to a few tens of metres thick in the supracrustals and occur as less regular masses in the 'granite'. Compositionally they vary from gabbroic to granodioritic, with the more mafic varieties being most common.

Granitic rocks exhibiting a variety of textural, structural and compositional characteristics underlie most of the area. Four main units are recognized: foliated (older), 'granite', 'leucogranite', feldspar augen 'granite' and pyritic mine 'granite'; however, in geological mapping these are somewhat arbitrarily differentiated due to transitional relationships and admixture of types. Although there is no unambiguous age data available for these 'granites', adjacent northshore 'granite' of geologically similar age yield Rb-Sr isochron dates around 2000 Ma.

The area is characterized by two major deformation events of which the earliest gave rise to the dominant regional foliation and to rare minor and outcrop scale folds. This foliation, which in general parallels compositional layering, is folded into the major Goldfields syncline, whose axis plunges weakly to moderately south. Related open minor folds have subvertical axial surfaces which are locally paralleled by a weakly defined schistosity. Most rocks display a pronounced rodding fabric, coaxial with second fold axes and apparently the product of this deformation event. However, a note of caution is introduced into this interpretation, as the rodding fabric is also parallel to first fold axes.

Peak metamorphism is marked by major recrystallization after the first deformation. Quartz-feldspar matrix fabrics, where little influenced by later deformation, are typically equigranular, equidimensional annealed aggregates. Prophyroblasts grow in random orientations within this felsic matrix. A variety of retrogressive metamorphic effects accompanied later events.

The mine 'granites' comprise lenticular sheets of leucocratic, homogeneous felsic rock typified by disseminated pyrite and cut by a stockwork of gold-bearing quartz veins. The Box 'granite' is in contact with quartzites and older 'granite', the Frontier with quartzites and the Athona with older 'granite' and amphibolite. Textures are metamorphic. Subhedral to euhedral porphyroblasts of quartz and feldspars (perthite and albite) are enclosed by an extremely fine grained (<0.1 mm) felsic matrix. Blast size varies from 0.5 mm in the Frontier to 2 to 5 mm in the Box and Athona 'granites'. Postcrystalline cataclasis during the second deformation is manifested by undulose extinction, suturing and locally primary recrystallization of quartz grains and by bending and fracturing of feldspars, chlorite (after biotite) and white mica. It is most marked in the Athona 'granite' and least apparent in the Frontier 'granite'.

Chemically the Box and Athona 'granites' resemble peraluminous alkali feldspar granites, whereas the Frontier can be classified as a quartz-rich granitoid (60 per cent quartz). Na/K ratios are around 0.6 and around 0.02 respectively.

The quartz veins include sulphides and gold and in the Box and Athona 'granites' also albite. Tourmaline, chlorite and hematite are other reported constituents. The veins vary from microscopic dilational gashes to planar bodies several centimetres in width and traceable over many metres. They are typically closely confined within the outcrop of the host 'granites'. Wall-rock alteration is neither megascopically nor microscopically apparent adjacent to veins although retrograde metamorphism apparently accompanied vein formation. Perthitic feldspar blasts, which have partially unmixed to microline-albite, are cross-cut and rimmed by albite. Chlorite (after biotite) is also characteristic.

Gold, typically associated with pyrite ± sphalerite ± galena ± chalcopyrite, occurs primarily in the quartz veins, but is also present in the wall rock. It is found free, in pyrite, and as coating on microfractures. Geochemically the mineralization is simple and expressed by Au ± Ag, Zn, Pb, Cu and Mo.

Considerable debate has surrounded interpretation of the 'granitic' rocks and of the mine 'granites' in particular, specifically, whether or not they are intrusive or the products of granitization. Transitional contacts with the supracrustals, especially quartzites, and between and within the different 'granitic' subdivisions themselves, together with the metamorphic quartz-feldspar blastic textures suggest the latter origin. Variations in 'granite' composition likely reflect degree of granitization and initial supracrustal composition. The 'granites' do not appear to have formed by isochemical reconstitution 'in-situ' from meta-arkosic precursors; rather, field relations suggest significant additional and subtraction of material. Similar phenomena have been reported in the peripheral regions of migmatite massifs and in aureoles around granite batholiths.

Also debated is the role of albilization in gold mineralization. In the nearby Beaverlodge area albilization phenomena are widespread and in many instances clearly related to the earliest generation of epigenetic pitchblende mineralization, which locally contains gold, (Martin Lake Mine) and is dated at around 1750 Ma. Albite and gold are associated in quartz veins at the Box and Athona deposits and small bodies of albitite with enhanced gold values are also reported in these 'granites'. In contrast, gold-bearing veins in the Frontier 'granite', which is sodium-deficient, lack albite. Thus, there appears to be no dependency of the two phenomena.

The gold mineralization may derive from either an existing concentration in the precursor supracrustals, or may have been introduced during granitization or quartz veining. To date, bedrock sampling has not identified significant gold anomalies in the supracrustals, although a variety of potentially auriferous sources can be envisaged. If gold was introduced , it likely took place during granitization and was subsequently redistributed during quartz veining. The following arguments are presented in favour of this hypothesis: 1) gold-quartz vein systems are restricted within specific 'granites', although quartz vein systems are widespread, 2) gold is not confined to quartz veins but is additionally present in the host 'granites', and 3) vein composition reflects host rock chemistry (e.g. $\pm$ Na = $\pm$ albite).

Also distinguished in and around the Goldfields area are pitchblende-bearing quartz veins which locally show gold and silver values. In the Box 'granite', these cross-cut the massive gold-pyrite-quartz veins. They are mineralogically complex and contain euhedral quartz, specular hematite, carbonates, chlorite, pitchblende, chalcopyrite, nickel arsenides, cobalt minerals and native gold and silver. Geochemically they are characterized by U $\pm$ Cu, Ni, Co, Zn, Pb, V, Y, Zr, Th, Ag, Au and Pt. Pitchblendes yield discordant Pb/Pb and U/Pb ages, however, the U/Pb data fall on a lead loss line with an upper intersection on concordia at 1150 Ma and a lower intersection at 290 Ma. These radiometric data, in conjunction with field observations, suggest that these veins are of sub-Athabasca unconformity type and thus much younger than the main gold mineralization event at goldfields and the early phase of pitchblende veining (ca. 1750 Ma) in the Beaverlodge area to the north.

Thomas, D.J. (1985): Geology of the Forsyth Lake (east) area; Saskatchewan Energy and Mines, Open File Report 85-4, 28p.

The area is underlain by rocks of Archean and/or Lower Proterozoic age which together form the Western Craton, a distinctive crustal block that is part of the larger Churchill structural province of the Canadian Shield. The geological history of the Forsyth Lake (east) area includes the early development of a supracrustal succession (the Bulyea Lake Supracrustal Suite) and the emplacement of a composite granitoid complex (the Apisis Lake Complex). Both have been intruded by syn- to post-tectonic mafic and granitic bodies.

The first deformational episode (D_1) is marked by a regionally developed gneissic foliation, and local schistosity, which are folded around tight to isoclinal east-trending axial surfaces (D_2) dipping moderately to the south. Refolding on northeast-trending axial surfaces (D_3) has produced a Type 3 fold interference pattern.

Northwest-trending second order shear zones (D_4), related to regional shearing, cut rocks in the extreme southwest part of the map area. North, northwest and north-northwest faults (D_5) form prominent lineaments in the region.

Metamorphic data indicate attainment of granulite facies conditions in the extreme southwest during the D_1 event, while middle to upper amphibolite facies conditions prevailed through D_2 and D_3. Retrogression of granulite facies rocks occurred during D_2 and/or D_3 episodes. Greenschist facies assemblages developed in retrogressed rocks cut by D_4 shears and D_5 faults.

A few occurrences of yellow uranium bloom occur in pegmatites along the Bulyea River.

Thomas, D.J. (in press): Geology of an area around Star Lake; Saskatchewan Energy and Mines, Open File Report 85-6.

The area is underlain by Precambrian rocks of the Central Volcanic belt, Crew Lake belt, and McLennan Group which form part of the larger La Ronge lithostructural domain.

The Central Volcanic belt portion of the Star Lake area is composed largely of metavolcanic units that grade laterally into volcanogenic and epiclastic metasedimentary rocks of the Crew Lake belt to the west. Along the southeastern margin of the Central Volcanic belt feldspathic meta-arenites and metaconglomerates of the McLennan Group structurally underlie the metavolcanics. The metavolcanic assemblage of the Star Lake area is characterized by a substantial thickness of basic to intermediate, submarine to subaerial pyroclastic deposits which increasingly give way to more flows and less pyroclastics southwards. Felsic metavolcanics make up less than 5 percent of the volcanosedimentary succession.

The volcanosedimentary complex has been intruded by a spectrum of relatively simple to complex basic to acid bodies. Field relations suggest an 'early', possibly subvolcanic, episode marked by composite intrusions ranging from gabbro-diorite to granite as well as by the emplacement of many of the ultrabasic to basic intrusions. A 'later' plutonic event is distinguished by more homogeneous uniform acid intrusions.

Metavolcanic rocks of the Star Lake area have a dominant calc-alkaline geochemical trend although a continuum from low potassium tholeiite through to calc-alkaline exists. The calc-alkaline rocks are typically high in Al and the suite as a whole is low in Ti. The geochemical evidence indicates volcanic rocks of the Star Lake area were emplaced in an island arc environment.

Major fold closures are not recognized in the Star Lake metavolcanic sequence although tight to isoclinal folds with northeast-trending axial surfaces are common in metasedimentary units west of the metavolcanics. Inhomogeneous strain characterizes much of the Star Lake area in the form of zones of extreme extensional fabrics, discrete shearing, as well as broader zones of cataclasis and structural slicing. Strain gradients are typically very steep throughout the area. Dilation structures tend to favour these zones of highly contrasting strain. Two northeast trending belts of intensely deformed rocks occur in the area; one extending through the Alpat Lake area (Alpat Lake Tectonic Zone) and the other along the west side of McLennan Lake (McLennan Lake Tectonic Zone). Late, brittle fracturing, faulting and shearing are widespread. Metamorphic data from the Star Lake area indicate that upper greenschist to lower amphibolite facies conditions were attained in the La Ronge Domain while at least middle amphibolite facies conditions were reached in rocks of the McLennan Group.

Gold — quartz vein mineralization appears to be related to dilation structures developed in shear zones within or along the margin of the Star Lake Pluton. The most important occurrences are the '21' zone, 'Pie' zone, Tamar showing and Jolu property. In addition to gold mineralization, several occurrences of pyrrhotite and chalcopyrite-pyrrhotite are present in the Star Lake area; notably in metagabbros at Neyrinck Lake and pelitic metasediments west of Alpat Lake.

Thomas, M.W. (1985): Compilation bedrock geology, Ile-a-la-Crosse, NTS area 730; Saskatchewan Energy and Mines, Report 245 (1:250,000 scale map with marginal notes).

Thomas, M.W. and Slimmon, W.L. (1984): Reindeer Lake South geological bibliography; Saskatchewan Energy and Mines, Data File 6.

Troyer, D.R. (1985): Peat resources in Saskatchewan; Saskatchewan Energy and Mines, Report 218, 74p.

A preliminary investigation of Saskatchewan peatlands was initiated in 1974/75. The investigation revealed numerous extensive peatland areas in central Saskatchewan for which there was little physical or chemical data. A reconnaissance peat resource program commenced in 1976 to assess the distribution, quantity and quality of fuel and moss peat resources.

The potentially economic peat areas of central Saskatchewan are concentrated in a wide belt on the Phanerozoic strata adjacent to the southern edge of the Precambrian Shield. Physiographically, the region consists of extensve uplands with intervening lowlands and plains. The peatlands in the upland regions are sparsely scattered and generally of small size. The lowlands and plains contain great concentrations of peatlands, some of which extend over vast areas.

Four geographic regions were selected as having the greatest potential for peatland development. Of these, the Buffalo Narrows- Beauval and the Pinehouse-LaRonge regions were subsequently surveyed. The peatlands in the two regions were selected for investigation on the basis of their size, vegetative cover, accessibility by helicopter and distance from potential markets. From 1978 to 1982, over 500 peatlands were investigated (seven of these in detail) for their peat type, thickness, humification, vegetative cover and subsoil type. Of these, 450 were sampled and over 200 analyzed for their suitability as sources of horticultural and energy peat. Radiocarbon dates were obtained from four deposits.

The resource calculations compiled from the accumulated data indicate enormous reserves of fuel

peat in the Buffalo Narrows- Beauval and Pinehouse-LaRonge regions. Although the majority of the fuel peat resources in the study regions are too distant from potential markets to be considered economically mineable in the foreseeable future, there are substantial resources which are accessible. Of most immediate significance for some northern communities is the prospect of displacing heating oil by an abundant, relatively cheap, indigenous domestic fuel supply. Such use, however, would probably have to be linked to a large industrial peatland development for economic reasons. Future prospects also include peat briquetting, peat coke, thermal power generation or a combination of these.

Many deposits in the regions have a high moss peat content, but most are too small or too shallow for economic consideration. Some are suitable for dual production of moss and fuel peat.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1985): U-Pb geochronology of the Trans-Hudson Orogen in northern Saskatchewan, Canada (abstract); presented at International Conference on Proterozoic Fold Belts, Darwin, Australia, August 1985.

The Trans-Hudson orogenic belt is a major Early Proterozoic tectonic feature of North America that is exposed from northern Alberta, Saskatchewan, and Manitoba to Greenland, with subsurface extension into the north-central United States. In northern Saskatchewan and Manitoba, the Trans-Hudson Orogen lies between the reworked Archean basement and associated Proterozoic cover of the northwestern part of the Churchill Province and the Archean Superior Craton to the southeast. Within this belt several apparent tectonic provinces, or domains, have been recognized. These include the Wathaman-Chipewyan Batholith, the Rottenstone Magmatic Belt, the La Ronge-Lynn Lake Volcanic Belt, the Glennie Domain, the Kisseynew Domain, and the Flin-Flon Domain, with smaller segments such as the Hanson Lake Block.

We have obtained U-Pb ages on zircons separated from several units within the Wathaman Batholith, Rottenstone Domain, La Ronge Volcanic Belt, Glennie Domain, and Hanson Lake Block. These data have aided considerably in reconstructing the orogenic history during the Early Proterozoic, in improved understanding of the relationships of the various terranes to one another, and the relationship of the Trans-Hudson Orogen to other Early Proterozoic orogens in North America.

Although earlier interpretations of the Glennie Domain and the Hanson Lake Block inferred the existence of substantial Archean cratonic basement to the Proterozoic supracrustal rocks (Lewry, 1981), we have found indications of Archean ages in only one unit, the Sahli Granite of the Hanson Lake Block. The data are equivocal, but the simplest interpretation is that granitic rocks about 2500 Ma old were subjected to granulite facies metamorphism about 1900 Ma ago, with substantial resetting of zircons. All other units originally thought to be Archean have proven to be Early Proterozoic, suggesting that Archean crust is a minor component of these two terranes.

The oldest apparent age for the Lower Proterozoic rocks is for a tonalitic gneiss (Davin Lake Tonalitic Gneiss Complex) in the Rottenstone Domain. Zircons from this unit suggest an age of about 1900 to 1950 Ma, but they are a complex population with distinct cores, so that the true age of this tonalite may be younger than 1900 Ma. Another, probably equivalent unit, yields a "clean" age of 1863 $\pm$ 12 Ma, consistent with the apparent age of 1900 to 1950 Ma being too old due to inherited zircon cores. This belt is just to the southeast of the reworked Archean craton, and inherited components would be expected if a rifted edge of the Archean craton or detrital material from it were involved in formation of these gneisses.

All other units studied in the region until now yield zircon ages of 1835 to 1890 Ma. Four metarhyolites from volcanic sequences yield ages of 1877 $\pm$ 8 to 1888 $\pm$ 12 Ma and include samples from the La Ronge Belt, Glennie Domain, and the Hanson Lake Block. Several of the associated gneissic and plutonic units yield similar ages and probably represent pre-volcanic and syn-volcanic plutons. The volcanic and syn-volcanic units are all strongly deformed. Later plutons, such as the Wathaman Batholith and other smaller units, yield ages of 1850 to 1870 Ma, constraining the peak of tectonic activity to about 1870 $\pm$ 10 Ma ago. A small, undeformed, discordant pluton yields an age of 1836 $\pm$ 7 Ma and represents the youngest unit dated at present. The results so far do not show any clear distinction in age among volcanic units or plutons of the La Ronge Volcanic Belt, the Rottenstone Domain, the Glennie Domain, or the Hanson Lake Block, suggesting that the distinction among these terranes is probably mainly lithologic and tectonic, rather than age.

All zircon ages are slightly older than recently reported Rb-Sr isochron ages on equivalent or the same units, suggesting some open system behavior in the Rb-Sr systems. The zircon ages for the main period of igneous and tectonic activity, 1890 to 1835 Ma ago, cover virtually the same age range as found for igneous units of the Penokean Orogen in northern Wisconsin of the southern Lake Superior region (Van Schmus, 1980) and are similar to the ages of 1900 to 1840 Ma found for igneous units of Wopmay Orogen in the Northwest Territories, Canada (Hoffman and Bowring, 1984). Thus, all three major Early Proterozoic orogens in the western part of North America formed at virtually the same time and probably record tectonic and igneous events associated with an Early Proterozoic assembly of that continental mass.

References:

Hoffman, P.F., and Bowring, S.A. (1984), *Geology*, 12, p68-72.

Lewry, J.F. (1981) *Nature*, 294, p69-72.

Van Schmus, W.R. (1980), *Geol. Soc. Amer. Spec. Paper 182*, p159-168.

Wilson, M.A. (1984): Depositional environments of the Mannville Group (Lower Cretaceous) in the Tangleflags area, Saskatchewan; *in* Oil and Gas in Saskatchewan, edited by J.A. Lorsong and M.A. Wilson; Saskatchewan Geological Society, Special Publication 7, p119-134.

Sedimentation of the Mannville Group in the area of Tangleflags Field was dominated by a succession of transgressive-regressive marine pulses. Sea level changes were, in turn, controlled by the interaction of basin subsidence, sediment influx and, probably, the effects of salt solution.

A detailed examination of cores in and around the Tangleflags Field indicates three main depositional environments; nearshore (characterized by swash-zone cross lamination), tidal (pin-stripe bedding, interlaminated silts and shales), and coastal swamp (carbonaceous shales, root zones, and coals). In the Tangleflags North Field, well developed "channel" sediments (fining-up sequences) are an anomalous feature. With the present well control it has not been possible to outline the limits of this feature.

The basic pattern of transgressive-regressive marine pulses has been influenced by minor tectonic warping associated with subsidence of the Western Canada Basin and/or local salt tectonism. There is clear evidence for structural activity both during and after Mannville time. Although they did not radically alter the pattern of Mannville sedimentation, tectonic events led to thinning and draping of sediments over local structural highs. Lithological sequences suggest that the structural highs were emergent more often and/or for longer periods than adjacent lows.

Farther east, in the area of Celtic Field, excellent core control shows a similar vertical sedimentary sequence to Tangleflags. In Celtic, however, the sediments show more marine and less terrestrial influence (cf. Lorsong, 1980).

Cross-Sections

Two series of cross-sections are being produced by staff of the Petroleum Geology Section:

1) Regional sections will employ wells more than 10 km apart and will eventually form a grid covering all the Phanerozoic portion of the province.

2) Local sections will employ wells less than 10 km apart and will be restricted to the petroleum-producing portions of the basin.

Each section will encompass one of four divisions within the Phanerozoic: Mesozoic (MZ), Mississippian (MISS), Devonian (DEV) and Lower Paleozoic (LP). Sections will be designated "W" or "E" depending on whether the area covered is west or east of the Third Meridian (Longitude 106^0). The identification number will also contain the year of preparation, as in the following example:

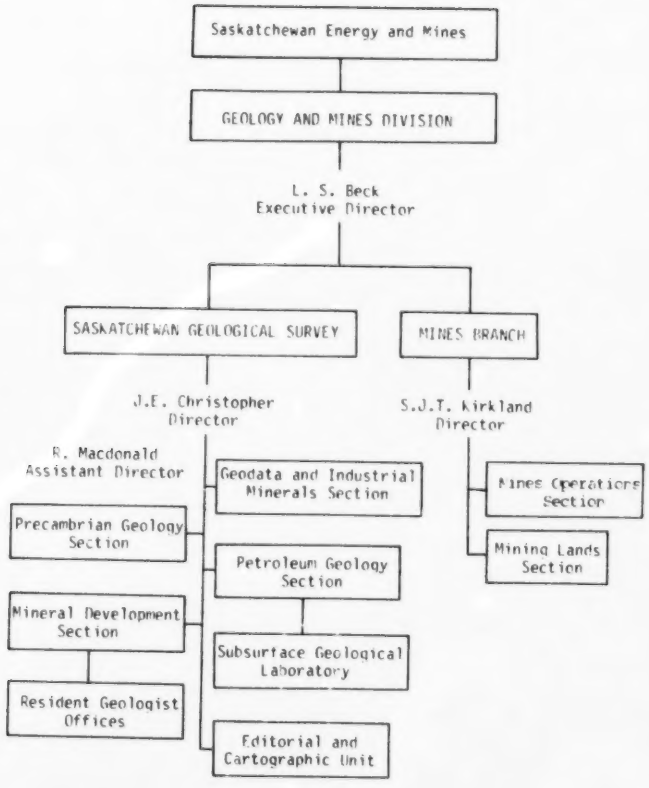
Local section MZ-W-84-1 - indicates a Mesozoic section with wells closer than 10 km prepared in 1984

Designation	*From*	*To*	*Length (km)*	*Strata*	*Author(s)*
MZ-W-84-1	A16-11-50-25W3	A03-30-47-25W3	30	L. Cretaceous	M. Wilson & R. Bennett
MZ-W-84-2	A10-34-50-24W3	A07-09-48-24W3	33	L. Cretaceous	M. Wilson & R. Bennett
MZ-W-84-3	06-36-50-26W3	02-33-47-26W3	31	L. Cretaceous	M. Wilson & R. Bennett
MISS-E-84-1	04-10-22-32W1	02-34-01-32W1	209	Mississippian	D. Lane
MISS-E-85-1	16-29-01-30W1	16-36-01-18W2	208	Mississippian	D. Lane
MZ-W-85-1	10-17-55-25W3	14-32-29-25W3	251	L. Cretaceous	M. Wilson, R. Bennett & V. Harris
MZ-W-85-2	15-01-32-29W3	05-27-32-16W3	125	L. Cretaceous	M. Wilson, R. Bennett & V. Harris
MZ-W-85-3	A04-12-49-28W3	03-15-48-15W3	125	L. Cretaceous	M. Wilson, R. Bennett & V. Harris
MZ-W-85-4	D10-16-40-28W3	11 17-40-15W3	125	L. Cretaceous	M. Wilson, R. Bennett & V. Harris

Acknowledgments

Senior assistants who assisted project leaders in the field are named on the accompanying maps. Full acknowledgement for assistance in the field is expected to be made in the final reports, where applicable.

The editors are grateful for assistance given in the editing and production of this report by Jim Christopher, Charlie Harper, Dave Thomas, Terri Uhrich, Bill Slimmon and Jagdish Bilkhu.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